In compliance with the
Canadian Privacy Legislation
some supporting forms
may have been removed from
this dissertation.

While these forms may be included
in the document page count,
their removal does not represent
any loss of content from the dissertation.

University of Alberta

Magnetostratigraphy of the Willow Creek Formation in south-western Alberta

by

Rabindra Thanju

A thesis submitted to the Faculty of Graduate Studies and Research in Partial fulfillment of the requirement for the degree of Master of Science.

Department of Earth and Atmospheric Sciences

Edmonton, Alberta

Fall 2003

University of Alberta

National Library
of Canada

Acquisitions and
Bibliographic Services

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale
du Canada

Acquisisitons et
services bibliographiques

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence
ISBN: 0-612-87896-1
Our file Notre référence
ISBN: 0-612-87896-1

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou aturement reproduits sans son autorisation.

Canadä

University of Alberta

Library Release Form

Name of Author: Rabindra Thanju

Title of thesis: Magnetostratigraphy of the Willow Creek Formation in south-western Alberta.

Degree: Master of Science

Year this Degree Granted: 2003

Permission is hereby granted to the University of Alberta Library to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly, or scientific research purposes only.

The author reserves all other publication and other rights in association with the copyright of the thesis, and except as herein before provided, neither the thesis nor any substantial portion thereof may be printed or otherwise reproduced in any material form whatever without the author's prior written permission.

Submitted: September 30, 2003

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Magnetostratigraphy of the Willow Creek Formation in south-western Alberta. Submitted by Rabindra Thanju in partial fulfillment of the requirements for the degree of Master of Science.

Date: Sept. 30, 2003

Abstract

The magnetostratigraphy of a 1420 m-thick section of the Willow Creek Formation in south-western Alberta was carried out on the 1800 m of section in five sub-sections. A total of 210 samples were analyzed from 70 sites (stratigraphic levels). Most of the samples were demagnetized with alternating frequency (AF), and some samples from channel sandstone showing heavy overprints were thermally demagnetized. AF demagnetization in steps of 5 mT up to 150 mT showed that the samples from most of the sites carried only low-coercivity viscous overprint, which was largely removed at 10 mT.

The magnetostratigraphy of the Willow Creek Formation in south-western Alberta was established after identifying the magnetic polarity chrons 30r, 30n, 29r, 29n, 28r, and 28n. The established sequence was correlated with those of the Scollard Formation in the Red Deer Valley, central Alberta by using the Geomagnetic Polarity Time Scale. The rate of sedimentation in south-western Alberta (Willow Creek Formation- 547 m / Ma) was calculated to be 16 times higher than that in central Alberta (Scollard Formation- 33 m / Ma).

The K-T boundary and the magnetic polarity chrons boundary between 30r and 30n were taken as stratigraphic time horizons in establishing magnetostratigraphy and correlation. Structural reference to the overlying Porcupine Hills Formation added stratigraphic control.

A number of short normal magnetic sub-zones were identified within the reversed magnetozone 29r, which had not been identified elsewhere. A short normal subchron, 29r.4n, was identified that embraced the K-T boundary. The

subzone was found to begin about 1.75 m above the boundary and to extend about 5 m below the boundary.

Acknowledgement

This final work for my Masters Degree in Science at the University of Alberta has been influenced by my excellent professors, through both their classes and my personal meetings with them.

I will never forget the honor and opportunity I had of working with Dr. Octavian Catuneanu, who is also my supervisor. I offer him my sincere thanks for all his efforts in helping me to complete this project.

My sincere thanks go to Dr. Jack F. Lerbekmo, who also played a significant role in this thesis. His tireless support and charming and balanced encouragement were always an inspiration. Once again, I thank him very much for introducing me to paleomagnetism and magnetostratigraphy.

I am very grateful to Dr. M. E. Evans for allowing me to use the paleomagnetic lab. I would like to thank Dr. Vadim Kravchinsky for his cooperation and stimulating ideas about the application of paleomagnetism. Dr. A. R. Sweet from the Geological Survey of Canada has also deserves credit for his palynological input and informative discussions about my work.

I would also like to thank my friends and colleague Daniela and Ahmed for sharing their thoughts and ideas with me throughout the year.

Last but not least, I am really thankful and grateful to my wife, Anju, for her year long continuous support while I was completing.

Table of Contents

CHAPTER ONE Page

1. Introduction 1

1.1 General 1

1.2 Previous work 1

1.2.1 General Stratigraphy.....2

1.2.2 Lithology.....3

1.2.3 Nature of Contact.....7

1.2.4 The K-T Boundary.....8

CHAPTER TWO

2. Principles and Methodology.....10

2.1 Principles.....10

2.1.1 Paleomagnetism.....10

2.1.2 The Earth's Magnetic Field and its Variations.....10

2.1.3 Principal Carriers of Magnetism in Rocks.....12

2.1.4 The Geomagnetic Polarity Time Scale (GPTS).....13

2.1.5 Instrumentation.....14

2.2 Methodology.....16

2.2.1 Sampling and Lab Preparation.....16

2.2.2 Data Acquisition and Analysis.....18

CHAPTER THREE

3. Database.....19

CHAPTER FOUR Page

4. Results and Interpretations.....21

4.1 Sections.....21

4.2 Station 9-Highway 22 section.....22

4.3 Station 10-Highway 22 section.....25

4.4 Station 14-Oldman River-Maycroft section.....25

4.5 Station 28Oldman River Dam Reservoir-Crowsnest River section.....28

4.6 Station 27-Castle River section.....29

4.7 Magnetostratigraphic Correlation.....36

4.8 Rates of Sedimentation.....37

CHAPTER FIVE

5. Discussion.....40

CHAPTER SIX

6. Conclusions.....43

References.....44

List of Figures Page

Figure 1.1 Location map of study area.....5

Figure 1.2 Location map of the sections.....6

Figure 1.3 General stratigraphy of the formation in the study area.....7

Figure 2.1 Specification of direction of geomagnetic field vector.....11

Figure 3.2 Variations of the geomagnetic field with time.....12

Figure 3.3 Geomagnetic Polarity Time Scale (GPTS).....14

Figure 4.1 Lithostratigraphy and magnetostratigraphy of the Station 9-Highway 22 section.....23

Figure 4.2 Directional behavior during AF step demagnetization of the samples from Station 9-Highway 22 section.....24

Figure 4.3 Lithostratigraphy and magnetostratigraphy of the Sation 10-Station 10-Highway 22 section.....26

Figure 4.4 Directional behavior during AF step demagnetization of samples from the Station 10-Highway 22 section.....26

Figure 4.5 Lithostratigraphy and magnetostratigraphy of the Station 14-Oldman River-Maycroft sectiontion.....30

Figure 4.6 Directional behavior during AF step demagnetization of the samples from the Oldman River-Maycroft section.....30

Figure 4.7A Lithostratigraphy and magnetostratigraphy of the Crowsnest River reservoir section of the Oldman River Dam (St. 28).....31

Figure 4.7B Lithostratigraphy and magnetostratigraphy of the Oldman River Dam Reservoir- Crowsnest River section.....32

Figure 4.7B Lithostratigraphy and magnetostratigraphy of the Oldman River Dam Reservoir- Crowsnest River section.....32

Figure 4.8 Directional behavior during AF step demagnetization of the samples from the Oldman River Dam Reservoir- Crowsnest River section.....33

Figure 4.9 Lithostratigraphy and magnetostratigraphy of the Station 27-Castle River section.....34

Figure 4.10 Directional behavior during AF step demagnetization of samples from the Station 27-Castle River section.....34

Figure 4.11 Magnetostratigraphic correlation between the strata of south-western Alberta and the Red Deer Valley.....35

List of Table

Table 4.1 Rate of Sedimentation in south-western Alberta and in central Alberta.....39

Appendix One

Table 1 Station 9-Highway 22 Section.....51

Table 2 Station 10 – Highway 22 Section.....53

Table 3 Station 14- Oldman River-Maycroft Section.....55

Table 4 Station 28-Oldman River Dam Reservoir-Crowsnest River Section.....56

Table 5 Station27-Castle River Section.....59

Appendix Two

A2.1 Magnetic behavior during alternating field (AF) step demagnetization of different sites in the station 9-Highway 22 Section I.....61

A2.2 Magnetic behavior during alternating field (AF) step demagnetization Of three samples from different sites in the station 9-Highway 22 Section II.....62

A2.3 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites in the station 9-Highway 22 Section III.....63

A2.4 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites in the station 9- Highway 22 Section IV.....64

A2.5 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites in the Station 10-Highway 22 Section. 65

A2.6 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites in the Oldman River-Maycroft Section.....66

A2.7 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites in the Oldman River-Maycroft .II.....67

A2.8 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites in the Oldman River-Maycroft III...68

A2.9 Magnetic behavior during alternating field (AF) step demagnetization of hree samples from different sites in the Oldman River Dam Riservoir (ORDR) Crowsnest River section I.....69

A2.10 Magnetic behavio during alternating field (AF) step demagnetization of three samples from different sites in the Oldman River Dam Reservoir (ORDR) Crowsnest River section II..... .70

A2.11 Magnetic behavior during alternating field (AF) step demagnetization of three s amples from different sites in the Oldman River Dam Reservoir (ORDR) Crowsnest River section III.....71

A2.12 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites in the Oldman River Dam Reservoir (ORDR) Crowsnest River section IV.....72

A2.13 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites in the Oldman River Dam Riservoir (ORDR) Crowsnest River section V.....73

A2.14 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites in the station 27-Castle River section.....74

Appendix Three

A3.1 Map showing the Station 9 (Alt. 4600 m) and 10 (Alt. 4700 m) on the Highway 22 section.....76

A3.2 Photograph showing the Station 9- Highway 22 section. 77

A3.3 Photograph showing the Station 10-Highway 22 section. 78

A3.4 Map showing the Station 14- Oldman River-Maycroft section.....79

A3.5 Photograph showing the Station 14-Oldman River- Maycroft section....80

A3.6 Airphoto showing the sections in the Crowsnest River (Station 28) and the Castle River (Station 27).....81

A3.7 Photograph showing part of the Oldman River Dam Reservoir-Crowsnest River section.....82

A3.8 Photograph showing the station 27- Castle River section. 82

Chapter One

Introduction

1.1 General

This thesis investigates the magnetic polarity sequence of the Willow Creek Formation in south-western Alberta. The study area is located (Fig. 1.1) in south-western Alberta, mainly along Highway 22 and the Oldman River near Maycroft and the Crowsnest River reservoir section of the Oldman River Dam. These locations are shown in the NTS series of maps (1:250,000 scale) of Kananaskis Lakes, Lethbridge, Fernie and Gleichen. Geologically, the study area is situated in the western limb of the Alberta Syncline. The section of Highway 22 –Station 9 and Station 10 are situated at Latitude 50^0 2.2' and Longitude 114^0 9.5', and Latitude 49^0 55.5' and Longitude 114^0 05.5', respectively. Similarly, the Oldman River–Maycroft (St.14) section is situated at Latitude 49^0 47.7' and Longitude 114^0 07', and the Crowsnest River reservoir section of the Oldman River Dam is situated at the Latitude 49^0 36' and Longitude 114^0 04'– 114^0 06'. The Castle River section (St. 27) is situated at Latitude 49^0 34.1' and Longitude 114^0 3.4' (Fig.1.2). The main drainages in the study area are the Oldman River, Crowsnest River, and the Castle River.

1.2 Previous work

The Willow Creek Formation was first named and defined by G. M. Dawson in 1885 and described by Williams and Dyer (1930), Russell (1933, 1940), and Tozer (1956). G. M. Dawson in 1883 recognized the Willow Creek Formation on the basis of its red coloration. In 1884, he designated the type

section of the formation at the mouth of Willow Creek and on the neighboring part of the Oldman River in southern Alberta. Similarly, Williams and Dyer (1930) recorded the best exposures on the Oldman River east of Fort MacLeod, in the northern part of Twps.9 and 10, Rge.25 W4M. Farther west, in the Alberta Foothills belt on the Oldman River in Secs. 5 and 6, Twp.10 Rge.1 W5M, Douglas (1950) described an almost complete section of the lower part of the formation (Glass, 1990). Tozer (1956) pointed out that the formation developed on both sides of the Alberta Syncline, with a thick sequence in the disturbed belt on the west and a thinner, more gently dipping one on the east. The formation on the eastern side is unfossiliferous although it has the same lithology and depositional condition as that on the west side (Russel, 1965). Carrigy (1971) pointed out that the formation has been deformed along the axis of an asymmetrical synclinal structure with steeply dipping beds on the west side of the Porcupine Hills and gently dipping beds on the eastern side. The thickness of the formation varies with the position relative to the axis of the Alberta Syncline. Carrigy (1971) reported 1006 m (3300 ft) near the axis; Tozer (1953), reported that the thickness of the west side was 1375 m, Tozer (1956) calculated 1260 m (4135 ft) for the outcrop on Castle River on the west side. Russell and Landes (1940) reported that the thickness was 400 m for the flat-lying eastern limb.

1.2.1 General Stratigraphy

The Willow Creek Formation is underlain by the St. Mary River Formation and overlain by the Porcupine Hills Formation (Fig. 1.3). The nonmarine formations deposited in southern Alberta, from the younger to older

formations, are Porcupine Hills Formation, Willow Creek Formation, St. Mary River Formation, Bearpaw Formation, and Belly River Formation. This sequence is also called the "Post-Wapiabi Sequence".

1.2.2 Lithology

The Willow Creek Formation is a non-marine, fluvial depositional sequence of Maestrichtian to Paleocene age. It consists of an interbedded sequence of red, brown and olive-green bentonitic shales at the base, and sandy shale interbedded with lenticular green-grey, fine-grained, poorly sorted argillaceous subordinate calcareous sandstone. The variegated shales contain numerous calcareous concretions. The red coloration and the calcareous concretions give the Willow Creek Formation its characteristic appearance. The Cretaceous – Tertiary (K-T) Boundary divides the Willow Creek Formation into lower and upper members. The lower part consists mainly of fine-grained sediments, with a freshwater fauna of floodplain and lacustrine origin. Mudstone alternates with thin and tabular fine-grained sandstone units. These occur as small-scale coarsening-upward cycles of pond-fill origin (Jerzykiewicz, 1997). The upper member of the Willow Creek Formation consists of dark grey mudstone interbedded with thin layers of siltstone and fine-grained sandstone. Medium-grained sandstone layers are subordinate, but much more frequent in the upper part of the member near its contact with the Porcupine Hills Formation. The upper member of the Willow Creek Formation correlates with the Coalspur and Ardley coal zones of the central Foothills and plains, respectively (Jerzykiewicz, 1992).

Douglas (1945) divided the formation (823m) in the Foothills into five zones or members (A to E) in the Callum Creek and adjoining map area to the north. The basal zone A, 163m thick, is composed of green, grey and purple shale with interbedded grey, fine-grained sandstones. The sandstones beds are massive to cross-bedded. The shale is the dominant lithology in this zone with some carbonate concretions. Zone B (75m) consists of green, red and mottled green and red shales and soft, grey sandstones. Zone C (4.5-9m) consists of grey, coarse-grained, cross-bedded, conglomeratic sandstones. The three lower zones are well exposed along the Oldman River in Secs. 5 and 6, Tp.10, R.1, W.5 Mer. The two upper zones, D and E, are 578 m thick. Zone D is of similar lithology to that of Zone B, and in Zone E, the sandstone beds becomes harder, coarser and thicker while the shales change gradationally to darker and harder rocks. Tozer (1956) pointed out that the two distinct molluscan faunas from Zones B and D in the Castle River section are Maestrichtian in age. Only the fauna found in Zone E was dated as Paleocene in age (Tozer, 1956). Thus, the Cretaceous-Tertiary boundary occurs near the demarcation of Zones D and E of the Willow Creek Formation.

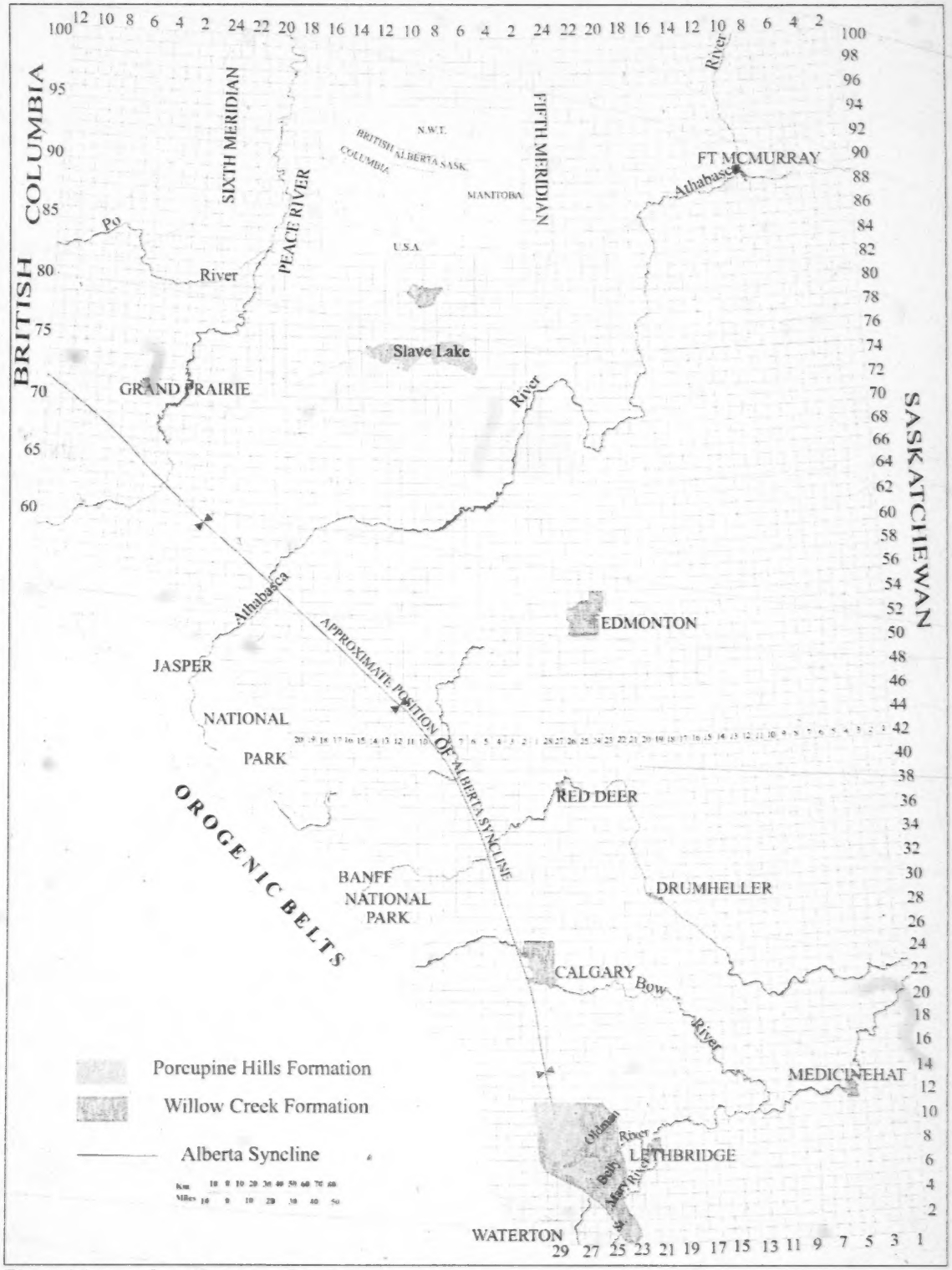

Figure 1.1 Location map of study area

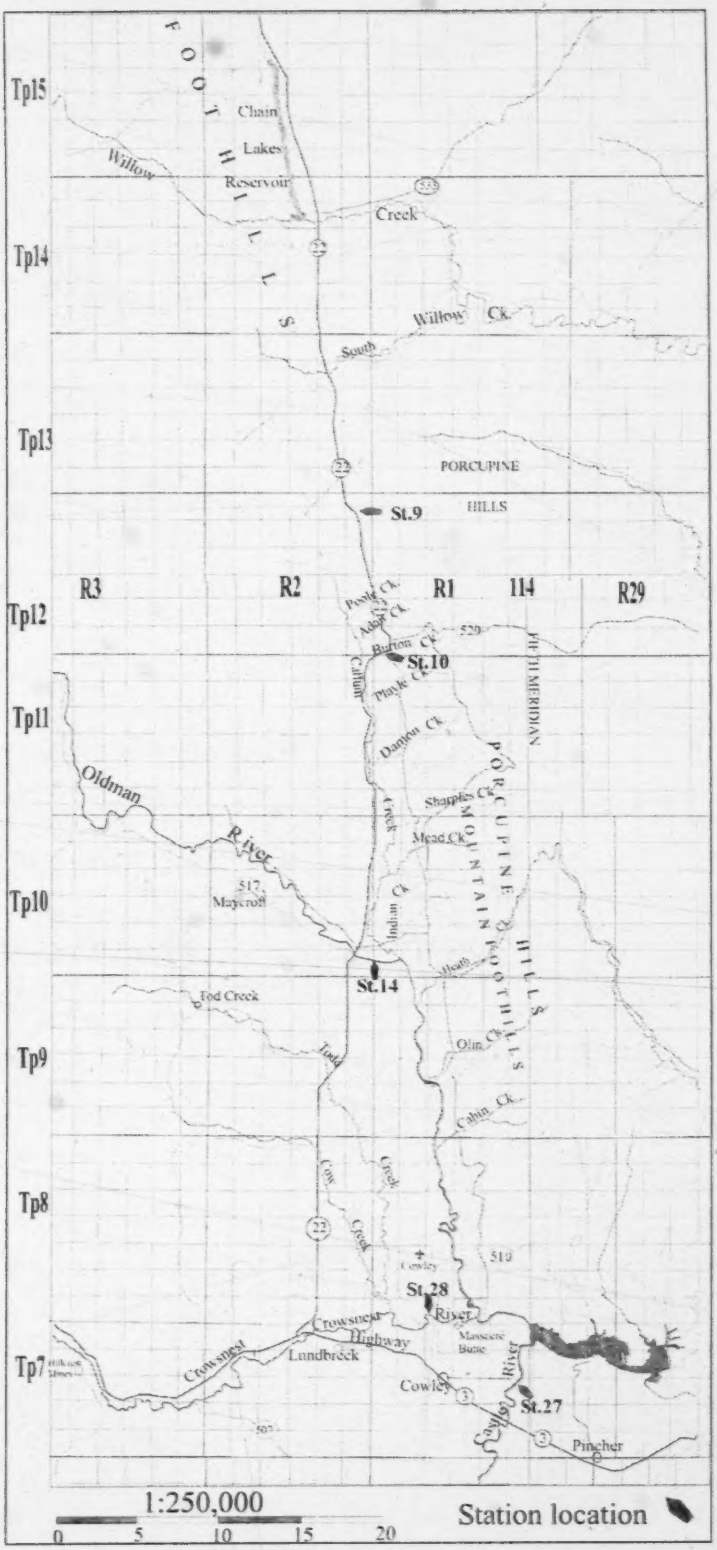

Figure 1.2 Location map of the sections. This map is taken from the NTS maps of 82 G,H, I, and J.

St.9 – Highway 22 section,
St.10- Highway 22 section,
St.14- Oldman River-Maycroft section, and
St.28- Oldman River Dam Reservoir (ORDR)–Crowsnest River section
St.27-Castle River section

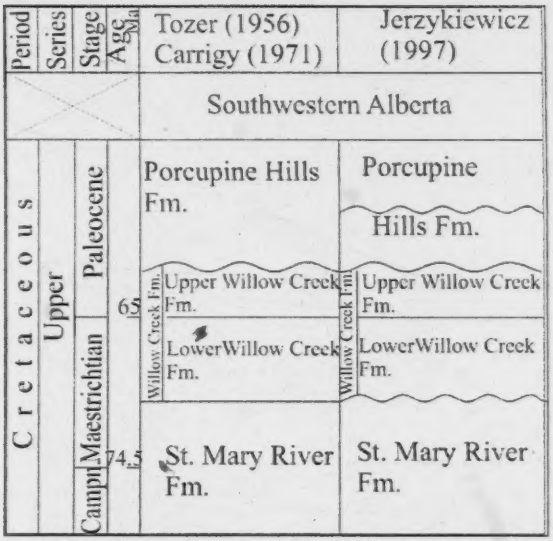

Figure 1.3 General stratigraphy of the formations in the study area.

1.2.3 Nature of Contacts

Different authors have expressed different ideas about the nature of the upper and lower boundaries of the Willow Creek Formation; however, the locations from which these authors observed this formation differed. It can be concluded that the nature of the contact is not the same regionally, due to the local variations in the erosional and depositional systems.

Although an early criterion used for defining the Willow Creek–Porcupine Hill boundary was the thickness and relative predominance of the sandstones (Bell, 1949); some authors stated that the boundaries were conformable and transitional (Williams & Dyer, 1930; Bell, 1949; Glass, 1990; Tozer, 1956; Wall & Rosene, 1977; McMechan & Stockmal, 1996). Others stated the boundaries were erosional and unconformable (Douglas, 1950; Bossort, 1957; Russel, 1965; Jerzykiewicz, 1997;).

The underlying contact with the St. Mary River Formation is transitional and conformable in the foothills belt on the west limb of the Alberta Syncline (Glass, 1990), but Russel (1965) suggested this contact may be erosional on the east side of the Syncline. The upper contact with the Porcupine Hills Formation appears to be transitional and conformable due to the similarity in lithology above and below and the assumed boundary (Glass, 1990). However, Douglas (1950) indicated that the contact between the Willow Creek and Porcupine Hills Formations is an erosional unconformity in the Callum Creek and Langford Creek map-areas in the southern Alberta Foothills. Carrigy (1971) found that, this interpretation was supported by the geophysical and drilling data cited by Bossort (1957). Bossort (1957) suggested that the base of the Porcupine Hills Formation in the southern Porcupine Hills is an erosional unconformity of considerable magnitude, which is a postdated Laramide deformation in the area. On the other hand, on the basis of seismic reflection data across the Porcupine Hills, McMechan and Stockmal (1996) found that the boundary is conformable and diachronous.

1.2.4 The K-T Boundary

A detailed study of the magnetostratigraphy of the Scollard Formation in the Red Deer Valley, central Alberta was carried out by Dr. Lerbekmo. Lerbekmo (1996) also recognized a short normal subzone at the K-T boundary within the 29r reversed zone.

Sweet on the basis of palynology, determined the K-T boundary in the Castle River section to be about 150m upstream from the Crowsnest Highway bridge, on the right bank (Jerzykiewicz, 1997). This K-T boundary is drawn on the Blairmore Map of the NATMAP Project, open file map, and is extended to the north crossing of the Crowsnest River reservoir section of the Oldman River Dam. Another location of the K-T boundary was identified (Sweet, 2003, pers. comm.) during a field trip on May 22, 2003 at an old section of Highway 22. The lower part of this K-T boundary was dated as Late Maestrichtian based on the presence of the index species Aquilapollenites conatus, A. redicutus, Letptopecopites pocockli, Myritipites scabratus, Orbiculapollis lucids and Wodehouseia spinate. However, no species were present that definitely indicate the rocks to be Paleocene. Hence, the location of the K-T boundary is tentative.

Chapter Two

Principles and Methodology

2.1 Principles

2.1.1 Paleomagnetism

Paleomagnetism is the study of the remanent magnetism of a rock to identify patterns of changes in the earth's magnetic field in the past. Throughout geological history, the earth's magnetic field reversed its polarity at irregular intervals. A record of the successive polarity changes is provided in the permanent magnetism of the sequences of sedimentary and igneous rocks and also in the pattern of magnetic anomalies produced in the ocean basin by sea-floor spreading. As a result, the geomagnetic polarity time scale provides an important global time scale and also a potential basis for identifying true 'time planes' in geological sequence, thus providing a basis for geological correlation.

2.1.2 The Earth's Magnetic Field and its Variations

The study of the nature and variation of the magnetic field with time, and its record throughout geological history, forms the basis of magnetic stratigraphy.

The geomagnetic field is a vector that fluctuates both in direction and intensity on a number of different time scales. The direction of the geomagnetic field, F, at any point on the earth's surface is defined by two angles (Fig. 2.1), the declination (D, specified relative to geographical north), and the inclination (I, specified relative to the horizontal, and regarded as positive if the field is downward-directed and negative if upward-directed in the northern hemisphere).

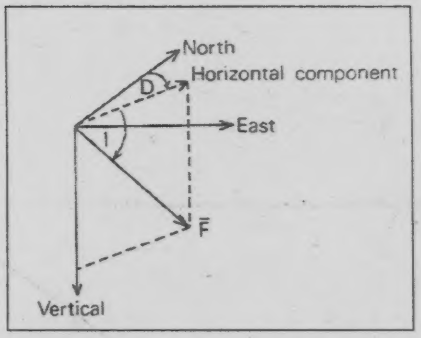

Figure 2.1 Specification of direction of geomagnetic field vector, F, in terms of angles of declination (D) and inclination (I) (Hailwood, 1989).

The directional variations of the geomagnetic field with time are summarized in Fig.2.2. Perhaps the most useful geomagnetic field changes from a stratigraphical point of view are polarity reversals (Hailwood, 1989). The normal polarity occurs when the magnetic north pole is lying close to the geographical north pole; when the magnetic south pole lies close to the geographical south pole, the polarity is referred to as the "reversed polarity" state. Reversals are observed from Precambrian times to the present, although the frequency of reversals seems to change considerably over time.

During a change in polarity from normal to reversed, the transition period is about 5000 years. The strata within the transition zones cannot be correlated globally; therefore, the ultimate resolving power of magnetostratigraphy is roughly equal to the duration of the transitions. The magnetic field sometimes appears to undergo an excursion characterized by a short-term major change in direction that may approach 180 degrees before returning to its previous direction. Since excursions are thought to have durations of about 1000 years, they offer the potential of providing very sharp stratigraphic markers. However, they are difficult to trace globally. Excursions and deformation of rocks cause anomalous

paleomagnetic directions (Versub & Banerjee, 1977, Banerjee, Lund & Levi 1979).

TIME SCALE OF FLUCTUATIONS, OR RECURRENCE INTERVAL	NATURE OF VARIATION	SOURCE
< 5 years	Transient field fluctuations	External (solar activity)
$10^2 - 10^4$ years	Secular variations and geomagnetic 'excursions'	Internal (core processes)
$10^4 - 10^7$ years	Polarity reversals	
$10^7 - 10^8$ years	Polarity bias and reversal frequency.	

Figure 3.2 Variations of the geomagnetic field with time (Hailwood, 1989).

2.1.3 Principal Carriers of Magnetism in Rocks

Iron oxides and other compounds of hydroxides and sulphides of irons are the main minerals carrying remanent magnetism of rocks and unconsolidated sediments. Other rock forming minerals like phyllosillicates, amphiboles, and pyroxenes do not have the capacity to carry a remanent magnetism. Instead, they may contribute significantly to the induced magnetism of the rock, and therefore, to its magnetic susceptibility. After subsequent weathering, diagenetic or metamorphic processes, these minerals produce iron oxides carrying a component of remanent magnetism which dates from the time of alteration. A knowledge of the composition and processes of formation of magnetic minerals helps to understand the history of the magnetization of a rock unit.

The most important carriers of remanent magnetism in rocks are members of the magnetite-ulvospinel (titanomagnetite), and hematite-ilmenite (ilmenohematite) solid solution series (Hailwood, 1989). Deuteric exsolution in igneous rocks commonly leads to preferential formation of the end members of these series (e.g., intergrowths of magnetite and ilmenite). Low-temperature

oxidation may result in the formation of intermediate oxidation products such as maghemite (γFe_2O_3), which carries a relatively strong remanent magnetism. More extensive alteration, particularly in sedimentary rocks, ultimately tends to lead to the formation of hematite (αFe_2O_3), either by direct oxidation from magnetite, or through the formation of iron hydroxides such as goethite ($\alpha FeOOH$), which may later be reduced to hematite.

2.1.4 The Geomagnetic Polarity Time Scale (GPTS)

The geomagnetic polarity time scale consists of the ages of successive polarity reversals. If a distinctive set of reversals observed in a particular rock sequence can be matched unambiguously with an appropriate part of this GPTS, then the geological age of the beds containing a polarity reversal can be deduced.

The reversal sequence of the magnetic field was first calibrated for the last five million years by dating basalts of known polarity. For historical reasons, the polarity sequence has been broken down into times of dominantly normal polarity and times of dominantly reversed polarity. These time units are known as "chrons". One rather obvious application of the magnetic time scale is as a dating tool for stratigraphic sequences. The pattern of polarity zones is determined by measuring the magnetic vectors of samples taken from the stratigraphic section. If the polarity zones can be unambiguously identified, they constitute a precise temporal framework for sedimentary or volcanic sequences. Such records have proved invaluable for correlating stratigraphic information on a global basis, and are the primary means of calibrating the Mesozoic and Cenozoic evolutionary record with respect to time.

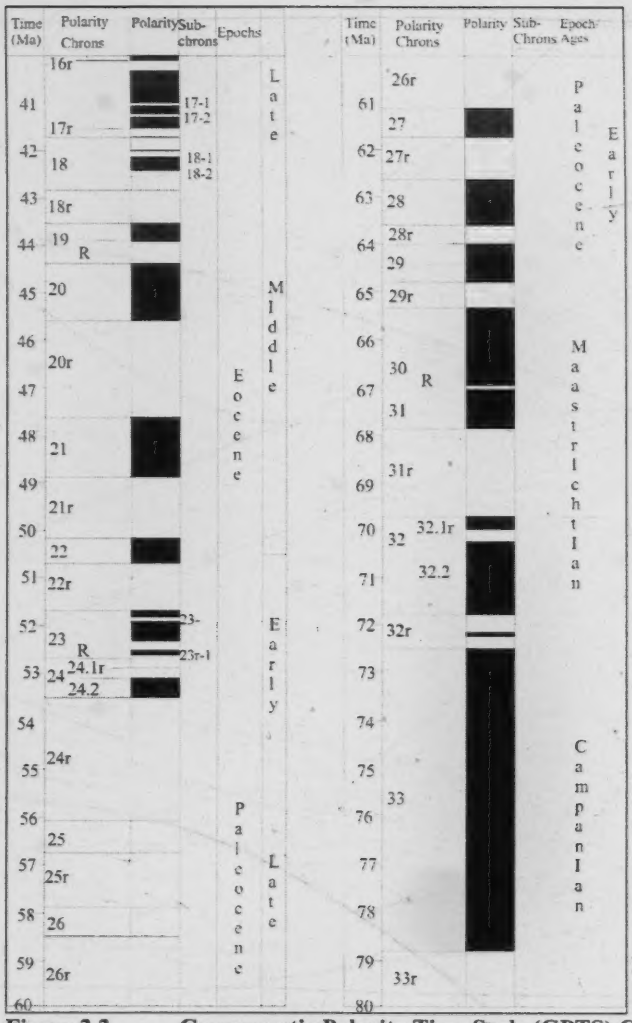

Figure 3.3 **Geomagnetic Polarity Time Scale (GPTS) Campanian To Eocene (Harland et al., 1990).**

2.1.5 Instrumentation

After preparing samples, the remanent magnetism of rock specimens was measured by means of a balanced fluxgate magnetometer. This is driven by a high- frequency alternating magnetic field, which is modulated by the weak direct field due to the rock specimens.

In the spinner magnetometer the specimen is rotated at a high frequency within a pick-up coil. The magnetic moment of the specimen induces an alternating voltage in this coil, and the direction and intensity of the component of magnetization within the plane of measurement can be determined from the phase and amplitude of this signal (Hailwood, 1989).

Rocks acquire different components of magnetization at different times in the earth's history. The components reside in different populations of magnetic mineral grains of the rock with different magnetic stabilities. The stability of the magnetism in a grain may be specified in terms of its blocking temperature or its coercivity (the remanent magnetism of the grain may be destroyed by the application of a particular magnetic field in the opposite direction to the magnetism, and the coercivity is a measure of this field) (Hailwood, 1989). Progressive demagnetization separates the different components of magnetism in the rock. The main three types of progressive demagnetization are alternating field, thermal and chemical demagnetization.

Alternating Field (AF) demagnetization is carried out sequentially along three orthogonal axes of the specimen, or alternatively, the specimen must be 'tumbled' during application of the alternating field, in order for it to be demagnetized uniformly throughout. This treatment is repeated at progressively higher applied fields, H1, H2, H3 etc. and the magnetization of the specimen is measured after each step. The applied alternating field increment is usually 5mT (50 Oerstds).

The thermal demagnetization technique involves heating the samples in a non-magnetic oven to predetermined temperatures in a magnetic-field-free space. The thermal fluctuations due to heating will randomize the magnetization of all grains with blocking temperatures up to the applied temperature. The magnetization of the specimen is then measured at room temperature, and the procedure is repeated at a slightly higher temperature in 50^0C or 100^0C temperature increments. This process may be continued until the magnetism of the specimen has been destroyed completely. The maximum demagnetization temperature is usually 500^0C.

2.2 Methodology

The methodology involves two stages of work: sampling and lab preparation, and data acquisition and analysis.

2.2.1 Sampling and Lab Preparation

Fieldwork was carried out in south-western Alberta. The five main sections studied in the area, were the Station 9-Highway 22 section, Station 10-Highway 22 section, Station 14-Oldman River–Maycroft section, Station 28-Crowsnest River Reservoir section of the Oldman River Dam and the Station 27-Castle River section. Some outcrops of a few meters of exposure were also studied in tributary creeks of the Castle River.

Before taking samples, the outcrop was located on the map, and all the information such as latitude, longitude, and altitude were recorded by using a GPS. The strata were measured by using a 1.5 m staff and measuring tape, and the

lithology in the stratal section was observed and described. The outcrop section was photographed both for detailed and general study by making a mosaic.

Oriented samples for paleomagnetic study were collected from different stratigraphic sites (horizons). Stratigraphic levels were determined by using a 1.5m staff. Soft rock samples were taken, using a method developed by Lerbekmo (1990). A 25 mm diameter-core barrel was driven into the rock after magnetic orientation. The rock sample cored in the barrel was collected in a vial with a 25mm diameter and 50 mm length. The magnetic north was scribed on the sample by the core barrel. Harder rock samples were collected as blocks after the orientation had been marked. At cored locations, three independently oriented samples per stratigraphic level were taken, whereas block samples were collected, three or more specimens were cut from the block. Sampling intervals ranged from station to station on the basis of accessibility and availability of exposures; the sampling ranged from 1- 5m to 10 – 25m.

The samples were labeled and brought to the Sedimentology Laboratory of Dr. Octavian Catuneanu. Samples were sawed into cylindrical specimens with a 25mm diameter and 25mm length. Laboratory measurements were done in the Catuneanu Lab and in the Petromagnetic Lab located in the Physics Department, where thermal demagnetization was also carried out. The soft rock samples were impregnated with sodium silicate solution to make them strong enough for the tests.

2.2.2 Data Acquisition and Analysis

Magnetic measurements were carried out on a Molspin spinner magnetometer. Most of the samples were demagnetized with progressive alternating field (AF) steps of 50 Oe (5 mT). Usually, the samples became too weak at 150 Oe to continue demagnetization. Some samples with high magnetic moment, after AF cleaning up to 150 Oe, were thermally demagnetized up to 300^0C.

The results of progressive demagnetization were plotted by stereographic projections of the change in direction of remanent magnetism. An Equal Area Polar Net was used to represent the progressive demagnetization direction. Some of the samples taken from channel sandstones showed high magnetic overprints, probably due to the presence of magnetic minerals such as hematite and magnetite. In this situation, the direction of magnetization did not change significantly; thermal demagnetization was carried out for those samples with heavy overprints. Normal polarity was determined if the magnetic dipole field pointed downward (to the lower hemisphere). Reversed polarity was determined when the dipole pointed upward (to the upper hemisphere). The inclination became shallow during the change in a polarity.

The magnetic polarity sequences were analyzed and interpreted by comparing these with those from the Geomagnetic Polarity Time Scale (GPTS) (Fig. 3.3).

Chapter Three

Database

The database consists mainly of the paleomagnetic results from the various strata of the Willow Creek Formation. The tabular form of the results is shown in Appendix 1. The lithostratigraphy and magnetostratigraphy of four sections and their correlations are presented in Chapter 4. The changes in the magnetic moment and direction with step AF demagnetization are shown in Appendix 3. All the rock samples were collected from outcrops. The strata were not completely exposed in any of the sections. The magnetostratigraphy of the Willow Creek Formation was interpreted after establishing the polarity sequences and correlating them between sections.

Five locations, Stations 9, 10, 14, 27 and 28, were chosen in order to study the Willow Creek Formation (Fig. 1.2). A total of 210 samples was analyzed from 70 sites of all the sections for paleomagnetic study. Stations 9 and 10 are situated on Highway 22. Station 10 is located about 12 km south from St. 9. Station 14 is located on the left bank of Oldman River about 2 km east of the Maycroft Bridge. Station 28 is situated on the Crowsnest River reservoir section of Oldman River Dam. The thickness of the St. 9 highway section was measured to be 112 m. Forty-four meters of strata occur at the St. 10 highway section. The stratigraphic section on the Oldman River was studied on both banks of the river up to the point where the river bends sharply toward the south. The total thickness of the strata was measured to be 180 m, out of which only 80 m of rocks are exposed. In the reservoir section, most of the outcrops were observed on the left bank of the

Crowsnest River. The total stratigraphic thickness of the Willow Creek Formation in this area was measured to be 1420m. The thicknesses of the missing sections were calculated by using trigonometry (distance X angle of dip).

Chapter Four

Results and Interpretations

4.1 Sections

A composite magnetic polarity sequence from five sections was correlated with that of the Scollard Formation, in the Red Deer Valley, central Alberta. This magnetostratigraphic correlation was based mainly on the finding of two absolute timelines in two different sections. Palynological studies of the area were previously found to be indeterminate and unyielding due to the semi-arid climatic conditions (Jerzykiewicz, 1989). Some new short normal magnetic sub-zones were also identified in the very thick sequence of sediment in south-western Alberta. The rate of sedimentation was calculated to be 10 times higher in south-western Alberta than in the Red Deer Valley, central Alberta.

The lithostratigraphy and magnetostratigraphy of the five sections are shown in Figures 4.1, 4.3, 4.5, 4.7 and 4.9. Their magnetostratigraphic correlation with the strata in the Red Deer Valley is shown in Figure 4.12. The general orientation of all sections is roughly NW to SE, which is more or less perpendicular to the orogenic belt. The first three locations are closer to the foothills, but all five locations are more or less situated in the foothills. All the sediments were deposited in fluvial-deltaic environments of over-bank deposits and sometimes crevasse splays, showing occasional pond fill origins (Jerzykewiecz, 1988).

The magnetostratigraphy and lithostratigraphy of the five sections are described and interpreted in the following sections.

4.2 Station 9-Highway 22 section

The total exposed stratigraphic thickness of the Station 9-Highway 22 section (Fig. 4.1) was measured to be 112 m, encompassing both Maestrichtian and Paleocene sediments. From the map, the total thickness of the Willow Creek Formation at this section was calculated to be 910 m (Fig. A4.1). From the map, the stratigraphic thickness from the lowest exposed strata to the boundary between the upper Willow Creek and the Porcupine Hills Formation was calculated to be 345 m (Figure A4.1).

Twenty sites were analysed from 112 m of strata. It is well known that the K-T boundary occurs in a reversed magnetozone 29r (e.g. Alvarez et al., 1977; Lerbekmo and Coulter, 1985a). The reversed zone within which the K-T boundary was inferred to be palynologically (Sweet, 2003, pers. comm.) was confirmed to be in a dominantly reversed magnetozone (Fig. 4.1). However, a number of the sites show normal polarity (e.g., 03AA, Fig. 4.1). These are presently located as sub-zones within 29r. The numbering of these sub-zones is very tentative and informal because of lack of the higher exposures. The short normal polarity sub-zone, 29r.4n of 7 m of mudstone, encompasses 5 cm of carbonaceous clay between 17 and 17.5 m (Sample no. 03AG in Fig.4.1), which Dr. A. R. Sweet believed to be the K–T boundary (pers.comm, 2003).

All the samples in this section showed normal polarity before AF cleaning. Except for samples 03AA and 03AG, they became reversed after AF cleaning at 5 mT or 10 mT (Fig. 4.2). The two exceptions remained normal even after demagnetizing up to 30 mT. The magnetic behavior during magnetic cleaning,

mostly to 15 mT from different sites, is shown in Figure 4.2. Most of the samples (except 03AA) showed decreasing magnetic moment with demagnetization, revealing that a soft viscous remanent magnetization (VRM) was being removed at relatively low demagnetization levels. Directional end points were adequately represented for polarity determination after 10 mT of AF demagnetization. Samples in transition zones are usually magnetically weak (Lerbekmo, 1999).

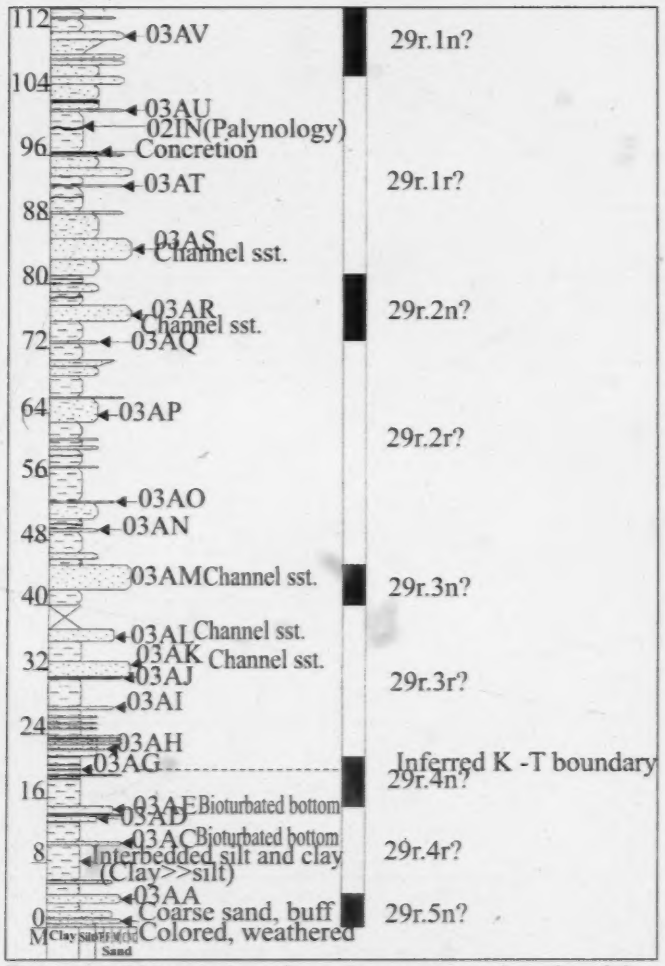

Figure 4.1 Lithostratigraphy and magnetostratigraphy of the Station 9-Highway 22 section.

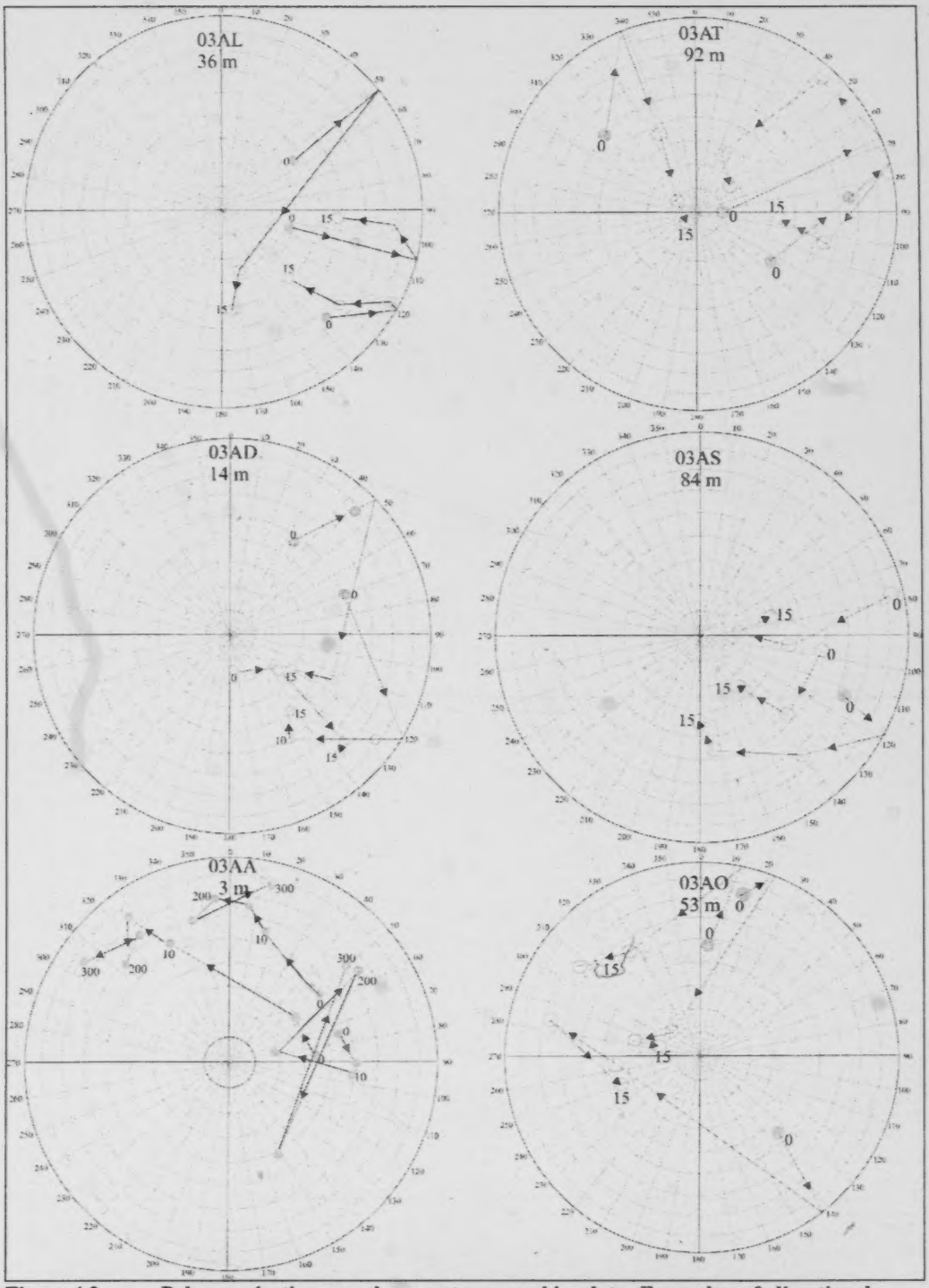

Figure 4.2 **Polar projection equal area stereographic plots. Examples of directional behavior during AF step demagnetization of samples from 6 representative sites in the St. 9-Highway 22 section. Solid dots on lower hemisphere, open circles on upper. Small one- and two- digit numbers are values in mT, and three-digit numbers are values in ^{0}C.**

4.3 Station 10-Highway 22 section

About 45 m of exposed Paleocene strata in the Station 10-Highway 22 section were measured and sampled. From the map, stratigraphic thickness from the lowest exposed strata to the boundary between the upper Willow Creek and the Porcupine Hills Formations was calculated to be 157 m. (Fig. A4.3). Station 10 is situated about 12 km south from Station 9. The base of the outcrop at Station 10 was calculated to be 76 m higher than the 112 m (Fig. 4.1) level at Station 9.

Twelve samples from 4 sites (10 A-E) were analyzed and found to be normal magnetozone and likely to be in magnetozone 29n (Fig. 4.3). The magnetic behavior during magnetic cleaning, mostly to 15 mT from different sites, is shown in figure 4.4. Samples 10A and 10E showed high magnetic moment, but soft viscous remanent magnetization (VRM) was being removed at relatively low demagnetization levels. Sampels 10B and 10C had low magnetic moment. Directional end points were adequately represented for polarity determination after 10 mT of AF demagnetization.

4.4 Station 14-Oldman River – Maycroft section

The total thickness exposed mainly on the right bank of the Oldman River-Maycroft section was measured to be 180 m, with 52 m of section missing in two intervals (Fig. 4.5). From the map, the total thickness of the Willow Creek Formation at this section was calculated to be 800 m (Fig. A3.4). The contact between the lower Willow Creek and the St. Mary River formations was inferred

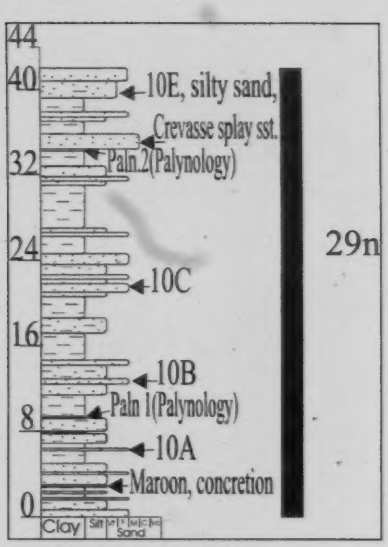

Figure 4.3 Lithostratigraphy and magnetostratigraphy of the station 10-Highway 22 section.

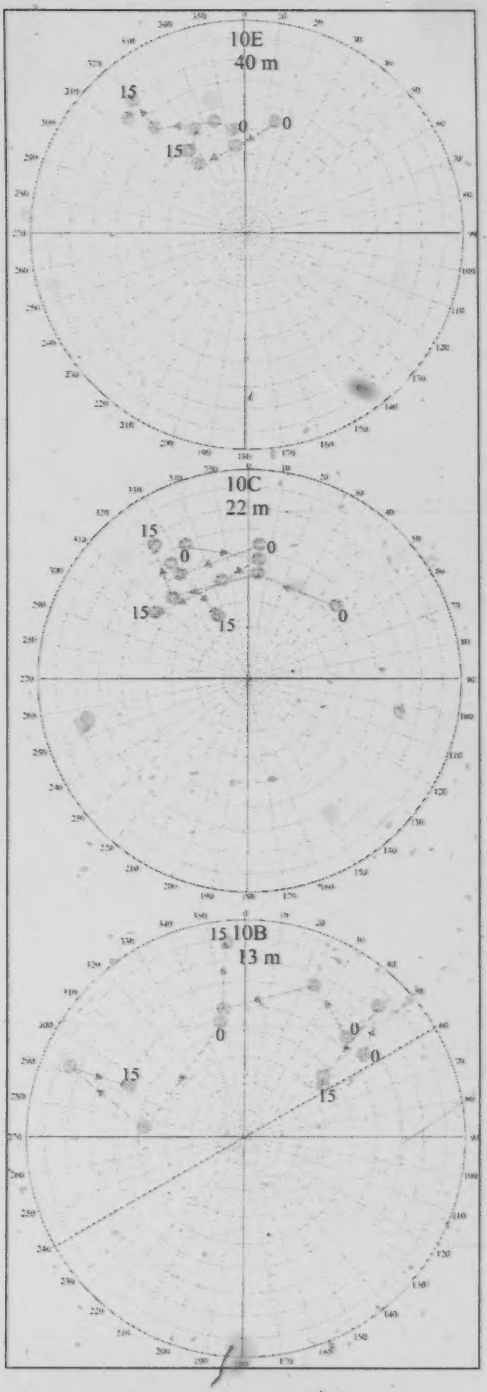

Figure 4.4 Examples of directional behavior during AF step demagnetization of samples from 3 representative sites (all normal) in the station 10-Highway 22 section.

by Jerzykiewicz (1997) at the 8 m level of Fig. 4.5. This contact was inferred on the basis of a possible tuff at 9 m (Fig. A3.4) and the findings of angiosperm pollen index species ScollaridiaTrapaformis. The presence of this palynomorph was taken to establish a correlation of the section with the upper part of the Horseshoe Canyon/Whitemud formations and hence correlated with the St. Mary River Formation.

The stratigraphic interval from 0 to 52 m was identified as a reversed polarity zone and are constructed to be 30r (samples 14L, 14A-14J). Above this three sites (14 J, K, L) normal polarity have constructed to represent 30n.

The contact between magnetozone 30r and 30n at 61 m is a timeline. This contact does not correspond with the formational boundary between the upper Willow Creek and St. Mary River formations as picked by Jerzykiewicz (1997). In the Red Deer Valley, the contact between the magnetozones 30r and 30n corresponds with the boundary contact between the Horseshoe Canyon and the Whitemud formations (Lerbekmo, 1985). The Willow Creek Formation and the St. Mary River Formation are roughly equivalent to the Scollard Formation and the Horseshoe Canyon Formation, respectively, in the Red Deer Valley, central Alberta.

The magnetic behavior during magnetic cleaning, to 15 mT at different sites, is shown in Figure 4.6. Most of the samples showed decreasing magnetic moment with demagnetization, revealing that a soft viscous remanent magnetization (VRM) was being removed at relatively low demagnetization levels. Some samples, 14F, 14I, 14J, 14K and 14M, showed a relatively higher

magnetic moment. Directional end points were adequately represented for polarity determination after 10 mT of AF demagnetization. Samples in transition zones are usually magnetically weak (Lerbekmo, 1999).

4.5 Station 28-Oldman River Dam Reservoir – Crowsnest River section

This longest and continuous section on the Crowsnest River and in the reservoir of the Oldman River Dam was measured to be 1420 m and consists of both Maestrichtian and Paleocene sediments. Lengths of covered intervals were calculated from the map. This section is situated in the reservoir. The formational boundary between the lower Willow Creek and the St. Mary Formation in this section was taken from the Blairmore Map of the NatMap project, open file series. A stratigraphic thickness of 380 m was calculated from the lower contact to the first sample, 28D, collected. The K-T boundary shown on the map lies at the 892 m, but was chosen to be at 820 m, at below a sandstone where 5-10 cm of organic rich black clay was observed.

Despite of difficulty of obtaining access and the lack of exposures, 35 sites were sampled and analyzed to establish magnetozones and correlate them with the magnetozones of other sections. A number of short reversed magnetozones are shown to occur within normal magnetozone 30n. At the 600 m level (Fig. 4.7A), the based of reversed magnetozone 29r is believed to occur.

A short normal polarity subzone 29r.4n? (Sample 02TH), encompassing 5 cm of carbonaceous clay was inferred to be the K-T boundary.

Samples 02OT, 02OQ, 02PO, and 02QJ were highly magnetically overprinted and thermally demagnetized up to 300^0C. Two samples, 02OS and

02OR, showed high magnetic intensity and reversal polarity before AF cleaning, but changed sto normal polarity at 50 mT. Most of the mudstone samples gave inconsistent polarity. For instance, two of the soft rock samples at 02MY reversed and one was indicated to normal, even though they were colleted from the same site. The fine-medium-grained sandstone samples are indicated to be more reliable than the cored soft rock sample in this area.

4.6 Station 27-Castle River section

About 55 m of strata of the uppermost part of the upper Willow Creek Formation were studied. A total of 3 sites were analyzed and found to be normal, probably magnetozone 28n (Fig. 4.9). This section is located on the right bank of the Castle River (Fig. A4.8), and this location is where the boundary between the upper Willow Creek Formation and the Porcupine Hills Formation is apparent.

The stronger magnetized samples (Samples 27B and 27C) contained a large proportion of a low-coercivity component, which was lost most rapidly at 5 mT.

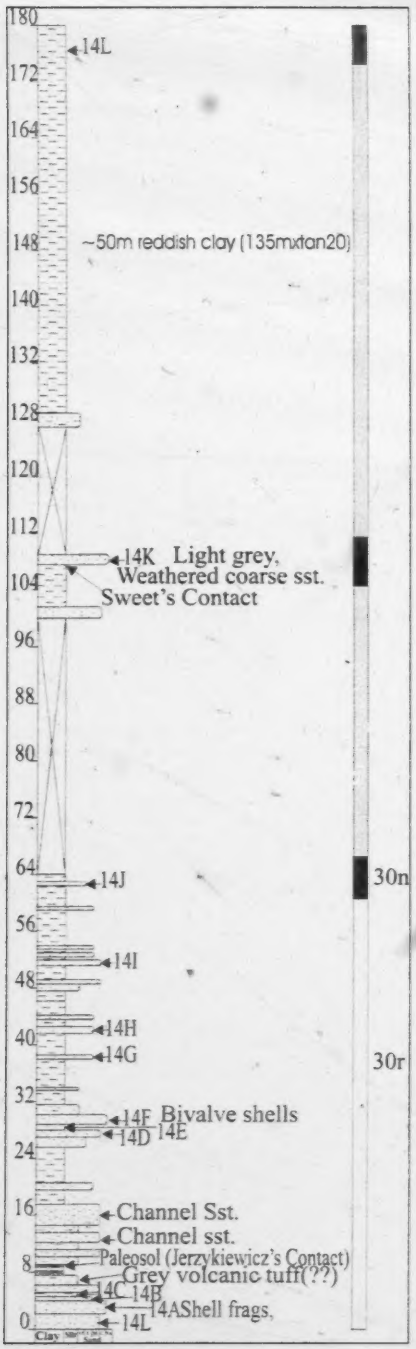

Figure 4.5 Lithostratigraphy and magnetostratigraphy of the Station 14-Oldman River-Maycroft section.

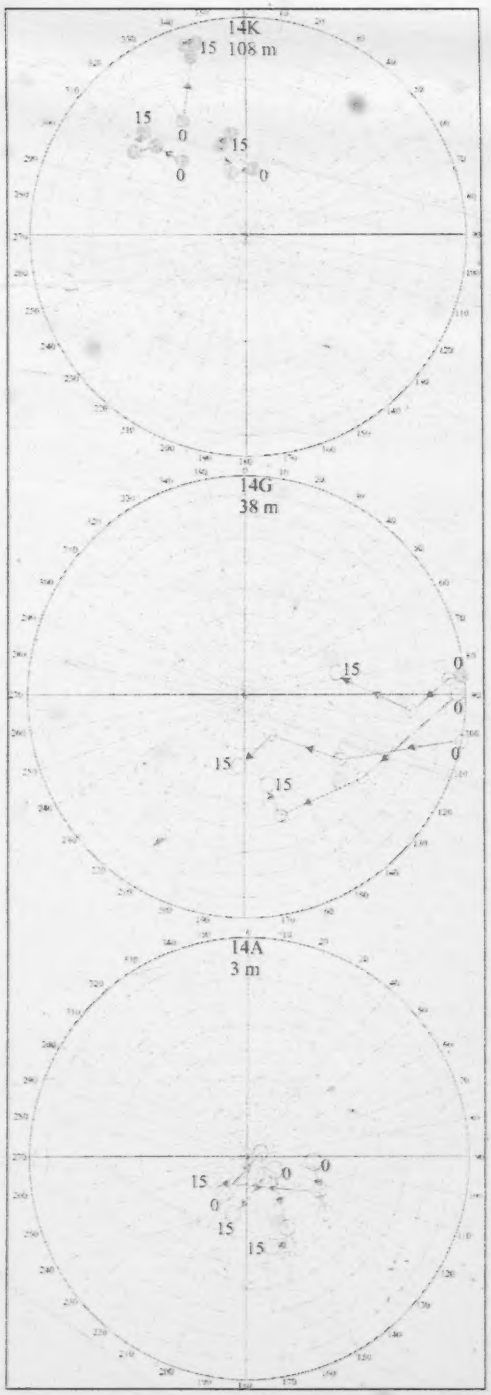

Figure 4.6 Examples of directional behavior during AF step demagnetization of samples from 3 representative sites (1 normal, 3 reversed) in the Station 14-Oldman River-Maycroft section.

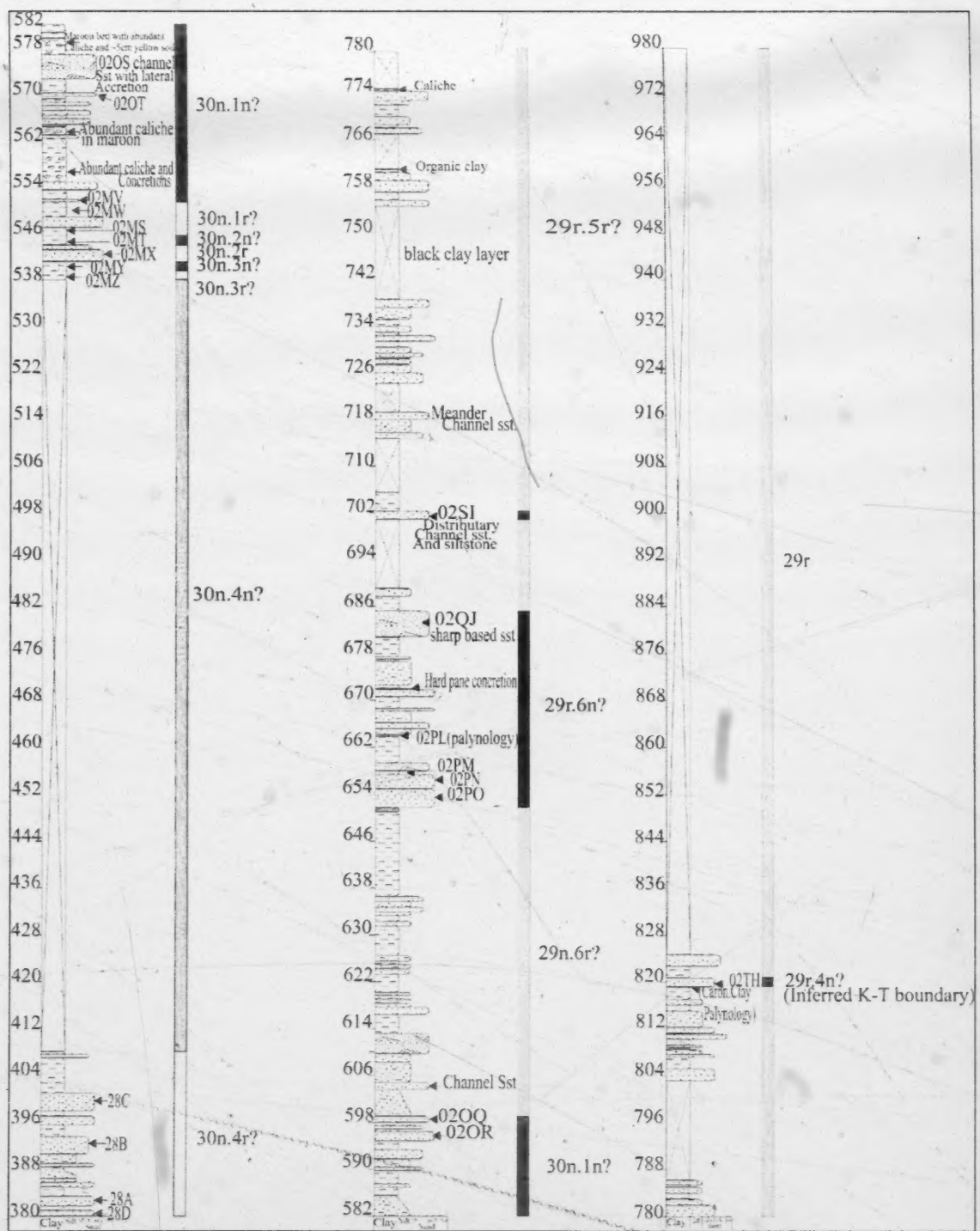

Figure 4.7A Lithostratigraphy and magnetostratigraphy of the Willow Creek Formation at the Station 28-Crowsnest River reservoir section of the Oldman River Dam. The missing stratigraphic section from 0-380 m was calculated from the map.

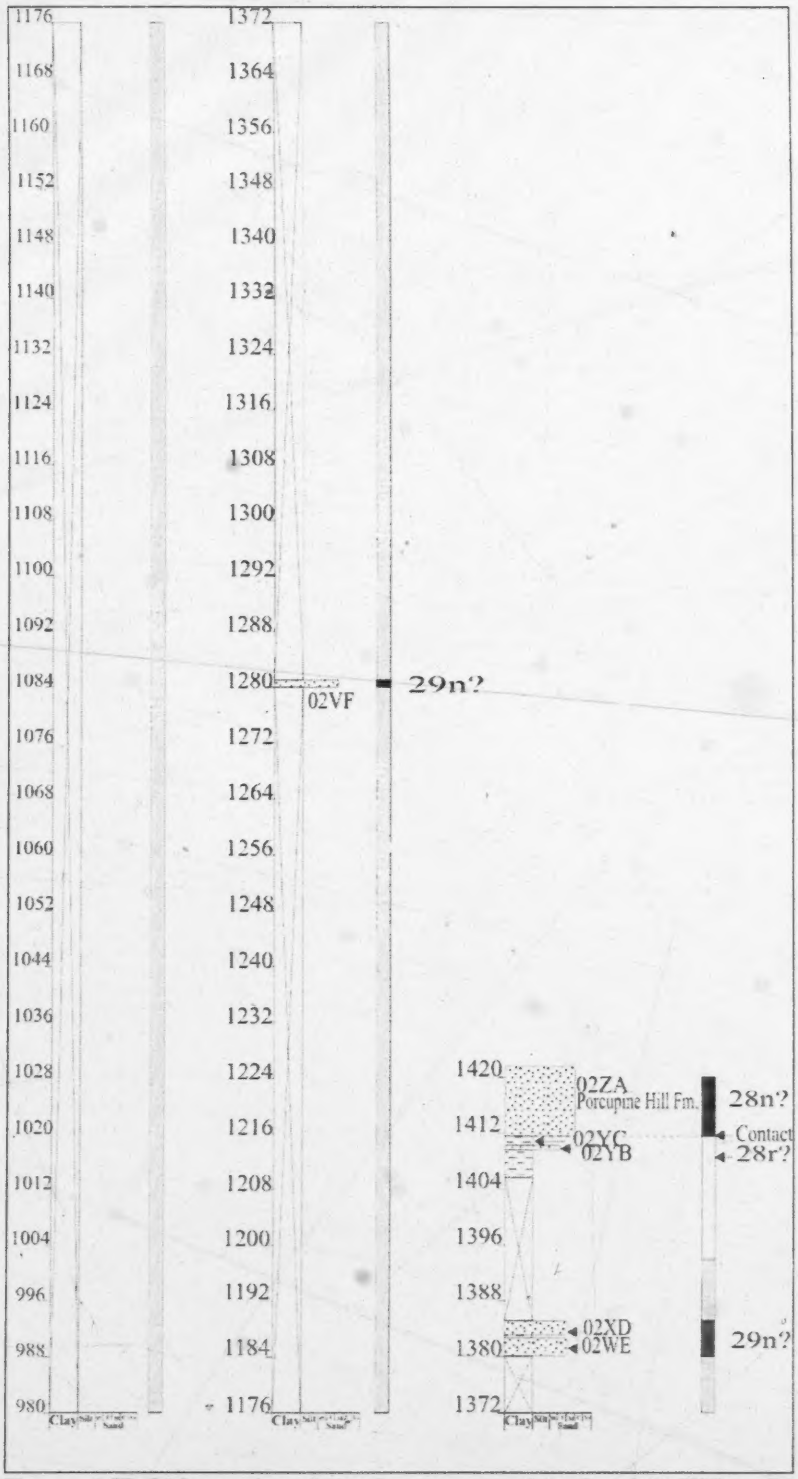

Figure 4.7B Lithostratigraphy and magnetostratigraphy of the Willow Creek Formation at the Station 28-Oldman River Dam Reservoir- Crowsnest River section.

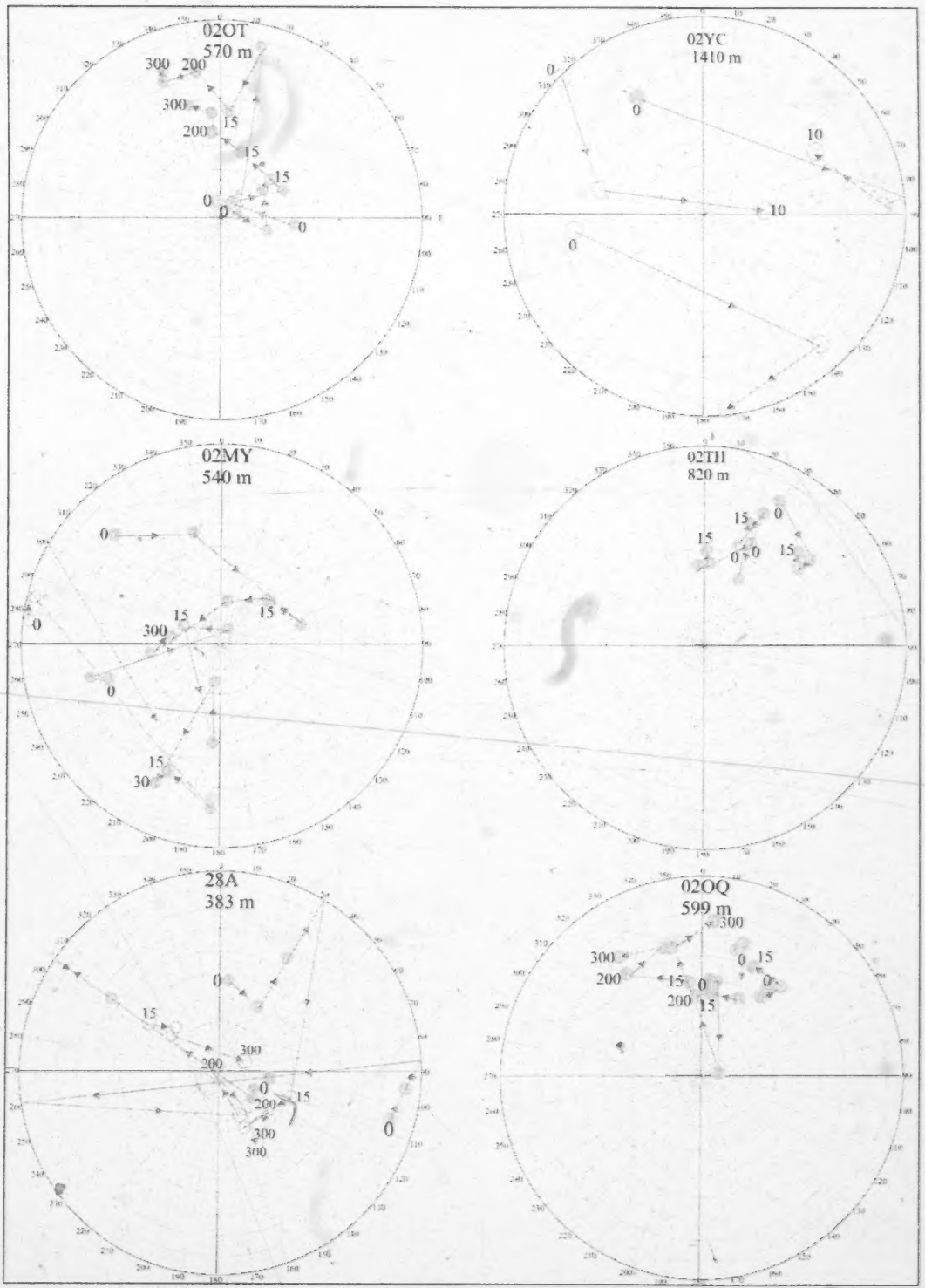

Figure 4.8 Examples of directional behavior during AF step demagnetization of samples from 6 representative sites (4 normal, 2 reversed) in the Station 28-Crowsnest River reservoir Section Oldman River Dam.

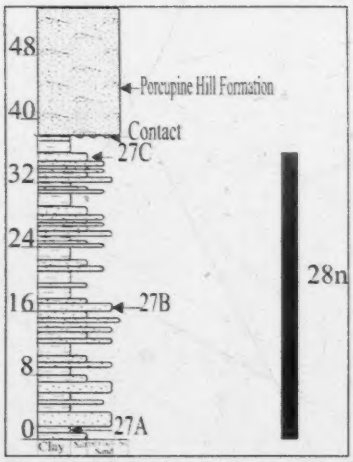

Figure 4.9 Lithostratigraphy and magnetostratigraphy of the Station 27-Castle River.

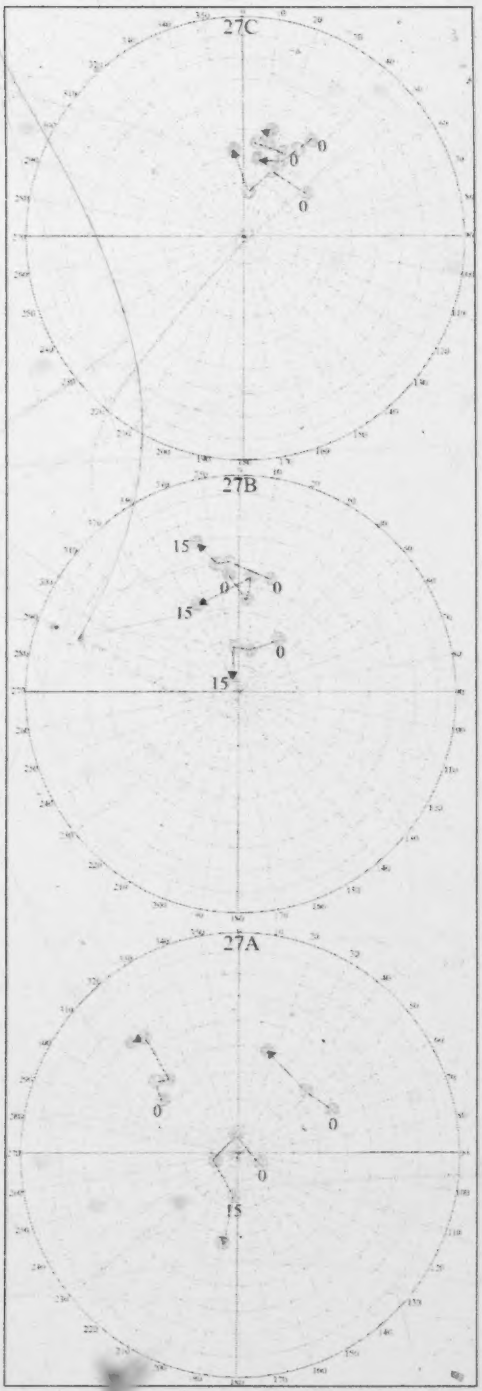

Figure 4.10 Examples of directional behavior during AF step demagnetization of samples from 3 representative sites (all normal) in the Station 27-Castle River section.

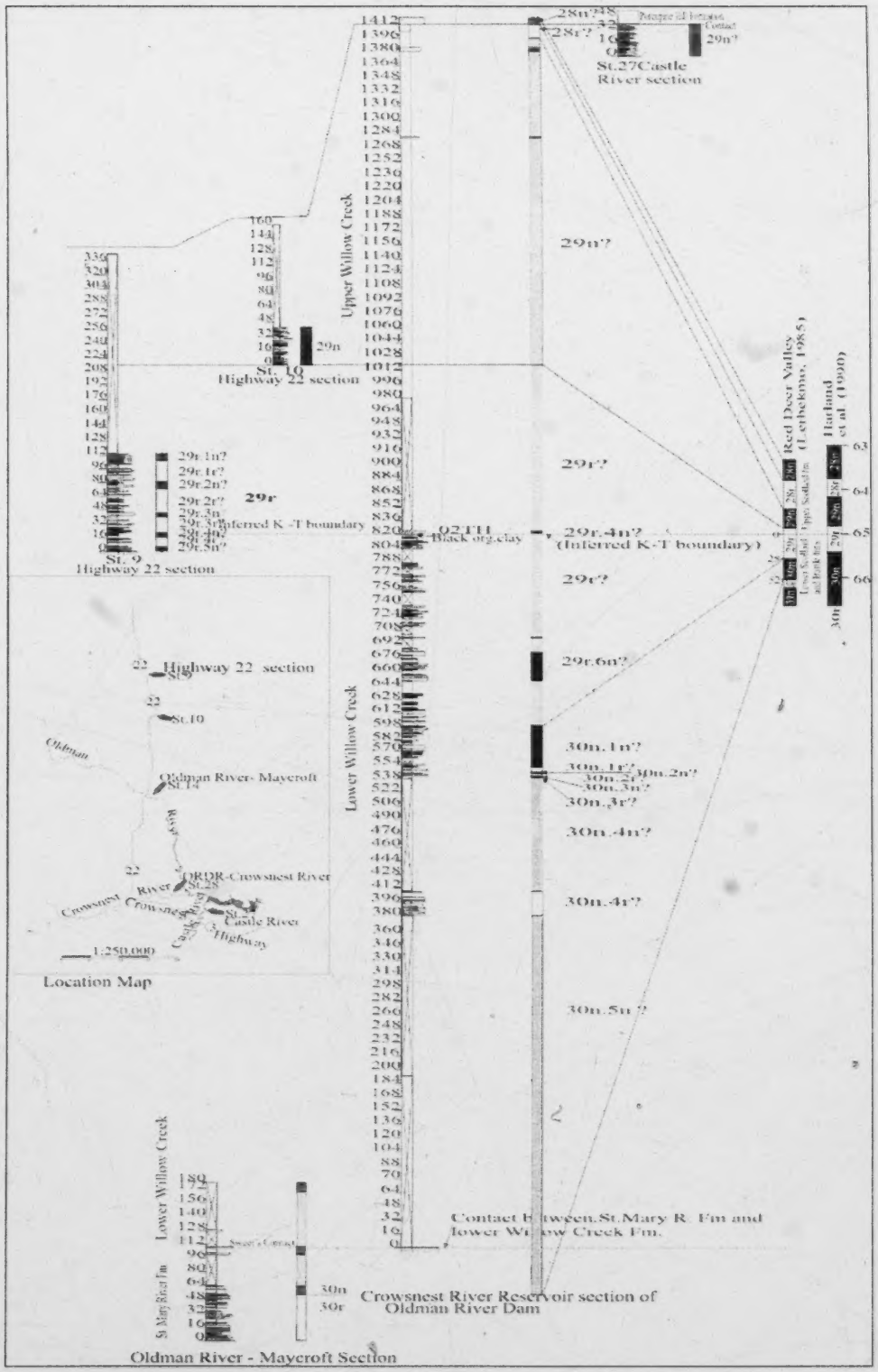

Figure 4.11 Magnetostratigraphic correlations between the strata of southwestern Alberta and the Red Deer Valley. Inset map shows the locations of the sections.

4.7 Magnetostratigraphic Correlation

Two time lines, the K-T boundary and the boundary between polarity chrons 30r and 30n, were determined by paleomagnetic study. These two time lines were used as stratigraphic control for establishing the magnetostratigraphy of the Willow Creek Formation in south-western Alberta. Another stratigraphic control was the contact between the upper Willow Creek and the Porcupine Hills formations. After establishing the magnetopolarity of the five sections, they were correlated with each other and then correlated with sections of the Scollard Formation of the Red Deer Valley, central Alberta (Fig. 4.11). A standard Geomagnetic Polarity Time Scale (Harland et al., 1990) was used in the correlation.

The first timeline, the K-T boundary, determined in the Station 9-Highway 22 section, was correlated with the K-T boundary of the Oldman River Dam Reservoir–Crowsnest River section. This boundary as determined from the map was shifted about 72 m lower on the basis of a black carbonaceous clay found at 820 m in a normal polarity interval.

The second timeline was the boundary between magnetozones 30r and 30n determined in the Oldman River-Maycroft section at 54 m. No evidence of a formational boundary was observed at this level. In the Red Deer Valley, the top of magnetozone 30r is the base of the Whitemud Formation (Lerbekmo, 1985). The contact indicated by Sweet at level of 108 m in Fig. 4.5 in the Oldman River-Maycroft section is correlated with the contact between the lower Willow Creek Formation and the St. Mary River Formation of the ORDR-Crowsnest River

section. However, this contact was determined from the map (Blairmore), and the stratigraphic section was calculated. From this correlation, about 600 m of section was considered to be magnetozone 30n in the ORDR-Crowsnest River section by comparison with the Geomagnetic Polarity Time Scale (Harland et al., 1990).

The top of the Castle River section has normal polarity (Fig. 4.9). The base of the overlying Porcupine Hills Formation is probably in magnetozone 28n or 28r, according to Lerbekmo and Sweet (2000, Fig. 21). Thus, the normal polarity zone at the top of the Castle River section is probably 29n.

Magnetozones 30n (20m), 29r (28 m), 29n (20 m), and 28r (26) in the Red Deer Valley, central Alberta (Lerbekmo and Coulter, 1985, Fig.3) were correlated respectively, with magnetozones 30n (650 m), 29r (420 m), 29n (384 m), and 28r (16 m) from the Crowsnest River reservoir section of the Oldman River Dam.

4.8 Rates of sedimentation

The rate of sedimentation for the lower Willow Creek Formation was calculated by using the time from the Geomagnetic Polarity Time Scale (GPTS) of Harland et al., 1990. The time of the contact between 30r and 30n is taken to be 66.6 Ma and that of the K-T boundary is 65 Ma according to the GPTS. The total stratigraphic thickness from the contact of the polarity chrons 30r and 30n to the K-T boundary is 50 m plus 820 m. Thus, the 870 m of sediment of the lower Willow Creek Formation was deposited in 1.6 m. y. Therefore, the rate of sedimentation is calculated to be 517 m / m. y. or 51 cm / 1000 yrs.

The rate of sedimentation for the lower Scollard Formation only was calculated to be 32 m / m. y. or 3 cm / 1000 yrs. Therefore, the rate of sedimentation for the Willow Creek Formation is calculated to be 16 times higher than that of the lower Scollard Formation. The rates of sedimentation in the foothills and adjacent areas of Alberta are generally higher than in the Plains due to tectonism and proximity to the orogenic belt.

The depositional periods of polarity chron 28r in the Willow Creek-Porcupine Hills formations section was calculated to be 325000 yrs whereas that of 28r in the GPTS was 400,000 yrs. Therefore, the top of 28r lags 75000 yrs of time which indicates there is an unconformity at the base of the Porcupine Hills Formation.

Table 4.1	Rate of Sedimentation in south-western Alberta and in central Alberta			
	Polarity Chrons	Thickness (m)	Time of Sedimentation(my) (From GPTS, Harland et al., 1990)	Rate of Sedimentation(m/my)
Willow Creek Formation Thickness=1470 m Duration of sedimentation =2.84 my Rate of Sedimentation=517 m/my	28r	16	0.4	40
	29n	384	0.668	575
	29r	420	0.58	724
	30n	650	1.2	542
	U.Willow Creek Fm.	600	1.23	488
	L.Willow Creek Fm.	870	1.60	544
Scollard Formation Thickness=90 m Duration of sedimentation=2.84 my Rate of sedimentation=32 m/my	28r	26	0.4	65
	29n	20	0.668	30
	29r	28	0.58	48
	30n	20	1.2	17
	U.Scollard Fm.	49	1.23	40
	L.Scollard Fm.	42	1.60	26

Chapter Five

Discussion

This research was the first study to find that in the Alberta Foreland Basin, reversed magnetic zone 29r consists of number of short normal magnetic sub-zones. The polarity sequence of the Red Deer Valley showed only one short normal magnetic sub-zone within the 29r reversed magnetic zone. The thickness of 29r in the Crowsnest River section is 12 times larger than that of the Red Deer Valley. Due to the condensed section at the Red Deer Valley, those short normal magnetic sub-zones are less likely to occur.

Jerzykiewicz (1997) placed the boundary between the St. Mary River Formation and Willow Creek Formation at the 8 m level of the stratigraphic interval, just above a grey stratum (Fig. 4.5), which he considered to be the equivalent of the volcanic Kneehills Tuff found in the eastern part of the formation. A different level at 107.5 m was proposed by Sweet (2003, pers. comm.) (Fig. 4.5), just below the grey coarse sandstone (Sample 14K) based upon angiosperm pollen index species of Scollardia Trapaformis and prominent red beds. These proposed boundaries lie roughly 50 m below and above, respectively, the 30r-30n boundary.

The Crowsnest River section of the Oldman River Dam is the most continuous section in the study area. However, most of the strata are covered and shown as missing sections in the vertical profiles. The stratigraphic thickness of the missing sections was calculated from the map. The K-T boundary drawn on the Blairmore Map (NatMap Project, open file series) lies at 892 m and in a

covered interval (Fig. 4.7A). This boundary might have been drawn on the basis of the K-T boundary found (Sweet, 1997) 150 m upstream from the Crowsnest Highway bridge on the right bank of the Castle River. The carbonaceous clay found just below the sandstone at 820 m (sample 02TH) was considered a likely K-T boundary. Palynology has shown that the sample from this site could belong to Paleocene or Maestrichtian time because age-definitive taxa were not observed (Report 03-ARS-2003, Sweet). The boundary between the upper Willow Creek Formation and the Porcupine Hills Formation is placed at the base of a major sandstone body.

Palynologically, the Willow Creek and Porcupine Hills formations' samples were typically unproductive or yielded a sparse flora characterized by the presence of a low diversity, spore-dominant assemblage (Jerzykiewicz and Sweet, 1986; 1988).

Due to insufficient outcrop exposure, the thicknesses of the tops and bottoms of many polarity subzones are not known. Some possible outcrop sections located in creeks along Highway 22 were not studied due to the lack of permission from the land owners.

The Crowsnest River reservoir section of the Oldman River Dam is the most continuous section that can be traversed, but most of it is covered. The Oldman River Dam has created a reservoir, so walking by the river bank is not possible. Samples collected in this section were discontinuous.

The continuous sequence of magnetic polarity in the Crowsnest River section could not be established due to the frequent missing intervals. However,

using a boat for sampling could enable researchers to study the section. The longest section that was missed for sampling in this study was 702 – 820 m (Fig. 4.7A). Some other sections such as those at 600-650 m ws also missed for sampling.

Hard rock samples were found to provide more consistent results than the cored mudrocks, so more sandstones should be sampled.

However, most of the channel sandstones have stronger overprints. For instance, samples 28D, 28A-28C, 02MY, 02MT, 02SI, 02MV, 02SI, 02SI, 02OT, 02OQ, 02PO, and 02PN possess a high magnetic moment and had to be treated with thermal demagnetization up to 300^0C.

Chapter Six

Conclusions

1. Identification of the following polarity chrons is believed to have been achieved: 29r and 29n in the Highway 22 section, 30r and 30n in the Oldman River-Maycroft section, 28r and 28n in the Crowsnest River reservoir section, and 28n in the Castle River section.
2. A number of normal magnetic sub-zones appear to be present in this expanded 29r section that have not been recognized elsewhere.
3. A K-T boundary in about 5 cm of carbonaceous clay is believed to have been found to occur within a normal polarity sub-zones 29r.4n in the Station 9-Highway 22 section and in the Crowsnest River reservoir section.
4. The contact between polarity chrons 30r and 30n, which in the Red Deer Valley occurs between the Horseshoe Canyon and Whitemud formations, does not correspond to an identifiable formation boundary in the study area.
5. The average rate of sedimentation of the lower Willow Creek Formation in south-western Alberta was calculated to be 547 m / m. y., which is 16 times higher than that in central Alberta.
6. Magnetostratigraphy was shown to be applicable to this deformed succession in the Foothills, particularly in the finer-grained sandstones.

References

Banerjee, S. K., Lund, S. P., and Levi, S. 1979. Geomagnetic record in Minnesota lake sediments; absence of the Gothenburg and Erieau exursions. Geology (Boulder). 7; 12, P. 588-591.

Catuneanu, O. and Sweet, A.R. 1999. Maastrichtian-Paleocene foreland basin stratigraphy, Western Canada: A reciprocal sequence architecture. Canadian Journal of Earth Sciences, v. 36, p. 685-703.

Catuneanu, O, Sweet, A.R., and Miall, A.D. 2000. Reciprocal stratigraphy of the Campanian-Paleocene Western Interior of North America. Sedimentary Geology, 134, p. 235-255.

Dawson, F.M., Evan, C.G., Marsh R., and Richardson, R. 1994. Uppermost Cretaceous and Tertiary of the Western Canadian Sedimentary Basin. In: Geological Atlas of the Western Canadian Sedimentary Basin. G.D. Mossop and I. Shetsen (Comps.), Calgary. Canadian Society of Petroleum Geologists and Alberta Research Council, p. 387-406.

Dawson, G. M. 1883. Preliminary Report on the Geology of the Bow and Belly River Region, North West Territory, with Special Reference to the Coal Deposits; Geol. Surv., Canada, Rept. of Prog. 1880-82, pt. B.

Dawson, G. M. 1884. Report on the region in the Vicinity of the Bow and Belly Rivers, North West Territory; Geol. Surv., Canada, Rept. of Prog. 1882-83-84, pt. C.

Douglas, Robert J.W. 1981. Callum Creek, Langford Creek, and Gap-map areas, Alberta. Memoir. Geological Survey of Canada. 402, p 124.

Hailwood, E. A. 1989. Magnetostratigraphy. Geological Society Special Report No. 19. The Geological Society. Blackwell Scientific Publications. P. 84.

Iwuagwu, C.J. and Lerbekmo, J.F. 1984. Application of outcrop information to subsurface exploration for sandstone reservoirs; basal Belly River Formation (Upper Cretaceous), Alberta Foothills. In: The Mesozoic of middle North America. Stott, D.F. and Glass, D.J. (Eds.). Canadian Society of Petroleum Geologists. Memoir 9; P. 387-400.

Jerzykiewicz, T. and Sweet, A. R. 1988. Sedimentological and palynological evidence of regional climatic changes in the Campanian to Paleocene sediments of the Rocky Mountain Foothills, Canada. Sedimentary Geology, 59; p. 29-76.

Jerzykiewicz, T. and Labonte, M. 1991. Representation and statistical analysis of directional sedimentary structures in the uppermost Cretaceous-Paleocene of the Alberta Foreland Basin. In Current Research, Part B, Geological Survey of Canada, Paper 91-1B, p. 47-49.

Lerbekmo, J.F., Evans, M. E. and Baadsgaard, H. 1979. Magnetostratigraphy, biostratigraphy and geochronology of Cretaceous-Tertiary boundary sediments, Red Deer Valley. Nature, Vol. 279, p. 26-29.

Lerbekmo, J.F. and Coulter, K.C. 1984. Magnetostratigraphic and biostratigraphic correlation of late cretaceous to early Paleocene strata between Alberta and North Dakota. In: The Mesozoic of middle north America. D.F. Stott and D.J. Glass (Eds.). Canadian Society of Petroleum Geologists. Memoir 9, p. 313-317.

Lerbekmo, J. F. and Coulter, K. C. 1985a. Magnetostratigraphic and lithostratigraphic correlation of coal seams and contiguous strata, upper Horseshow Canyon and Scollard Formation (Maastrichtian to Paleocene), Red Deer Valley, Alberta. Bulletin of Canadian Petroleum Geology. Vol. 33, No.3, p. 295-305.

Lerbekmo, John F. and Coulter, Kenneth C. 1985b. Late Cretaceous to early Tertiary magnetostratigraphy of a continental sequence: Red Deer Valley, Alberta, Canada. Can. J. Earth Sci. 22, p. 567-583.

Lerbekmo, J. F. 1989. The Stratigraphic position of the 33-33r (Campanian) polarity chron boundary in southeastern Alberta. Bulletin of Canadian Petroleum Geology. Vol. 37, No. 1, p. 43-47.

Lerbekmo, J. F. et al. 1992. Magnetostratigraphy and Biostratigraphy of the Continental Paleocene of the Red Deer Valley, Alberta, Canada. Bulletin of Canadian Petroleum Geology. Vol. 40, No.1, p. 24-35.

Lerbekmo, J.F., Sweet, A.R. and Braman, D.R. 1995. Magnetostratigraphy of late Maastrichtian to Early Paleocene strata of the Hand Hills, south central Alberta, Canada. Bulletin of Canadian Petroleum Geology. 43; 1, pages 35-43.

Lerbekmo, J.F., Sweet, A. R., and Duke, M. J. M. 1996. A normal polarity subchrons that embraces the K/T boundary: A measure of Sedimentary continuity across the boundary and synchroneity of boundary events, in Ryder, G., Gastovsky, D., and Gartner, S., eds., The Cretaceous-Tertiary Event and Other Catastrophes in Earth History: Boulder, Colorado, Geological Society of America, Special Paper 307.

Lerbekmo, J.F. 1990. A tool for obtaining oriented samples of weakly to moderately indurated sedimentary rocks for paleomagnetic measurements. Sedimentary Geology, 66, p. 295-299.

Lerbekmo, J.F. 1999. Magnetostratigraphy of the Canadian Continental Drilling Program Cretaceous-Tertiary (K-T) Boundary Project core holes, western Canada. Can. J. Earth Sci. 36, p. 705-715.

Lerbekmo, J. F., Evans, M. E., and Hoyr, G. S. 1990. Magnetostratigraphic evindence bearing on the magnitude of the sub-Paskapoo disconformity in the Scollard Canyon-Ardley area of the Red Deer Valley, Alberta. Bulletin of Canadian Petroleum Geology. Vol. 38, No. 2, p. 197-202.

Lerbekmo, J.F. and Sweet, A.R. 2000. Magnetostratigraphy and biostratigraphy of the continental Paleocene in the Calgary area, southwestern Alberta. Bulletin of Canadian Petroleum Geology. 48; 4, Pages 285-306.

McMechan, M. E. and Stockmal G. S. 1996. Definition of a mappable contact between the Willow Creek and Porcupine Hills formations, southern Porcupine Hills, Alberta: a conformable boundary. In Current Research 1996-E; Geological Survey of Canada, p. 103-110.

Miall, A.D. 1996. The geology of fluvial deposits, sedimentary facies, basin analysis and petroleum geology. Springer-Verlag, New York, USA. P. 582.

McElhinny, Michael W. and McFadden, Phillip L. 2000. Paleomagnetism: Continents and Oceans. International Geophysics Series, Volume 73. Academic Press. Pp.386.

Nelson, H.W. 1968. Petrography of sandstone interbeds in the upper Cretaceous-Paleocene of Gulf Spring point. Bulletin of Canadian Petroleum Geology. Vol. 16, no. 4. p. 425-430.

Opdyke, Neil D. and Channell James E. T. 1996. Magnetic Stratigraphy. International Geophysics Series, Volume 64. Pp. 346.

Rice, D.D. and Cobban, W.A. 1977. Cretaceous stratigraphy of the Glacier National Park area, northwetern Montana. Bulletin of Canadian Petroleum Geology. Vol. 25, no. 4, p. 828-841

Russell, L.S., and Landes, R.W. 1940. Geology of the Southern Alberta Plains. Geol. Surv., Canada, Mem. 221.

Russel, Loris S. 1965. The problem of the Willow Creek formation. Canadian Journal of Earth Sciences. Vol. 2. p. 11-14.

Stott, D.F. 1984. Cretaceous sequences of the foothills of the Canadian rocky mountains. In: The Mesozoic of middle north America. D.F. Stott and D.J. Glass (Eds.). Canadian Society of Petroleum Geologists. Memoir 9, p. 85-107.

Sweet, A.R. and Braman, D.R. 1992. The K-T boundary and contiguous strata in western Canada: interaction between paleoenvironments and palynological assemblages. Cretaceous Research. 13, p. 31-79.

Tarling, D. H. 1983. Paleomagnetism: Principles and Applications in Geology, Geophysics and Archaeology. Chapman and Hall. Pp. 379.

Tizzard, P.G. and Lerbekmo, J.F. 1975. Depositional history of the Viking formation, Suffield area, Alberta Canada. Bulletin of Canadian Petroleum Geology, v. 23, no. 4, p. 715-752.

Tozer, E. T. 1952. The St. Mary River – Willow Creek Contact on Oldman River, Alberta. Geological Survey of Canada, Paper 52-3. Pages 9.

Wall, John H. and Rosene, R.K. 1977. Upper Cretaceous stratigraphy and micropaleontology of the Crowsnest Pass, Waterton area, southern Alberta. Bulletin of Canadian Petroleum Geology. Vol. 25, no. 4, p. 842-867.

Williams, G.D. and Burk, C.F. 1964. In: The Geological History of Western Canada, Chapter 12, R.G. McCrossan and R.P. Glaister (Eds.). Alberta Society of Petroleum Geologists, p. 169-189.

Williams, M. Y., and Dyer, W. S. 1930. Geology of Southern Alberta and Southwestern Saskatchewan; Geol. Surv., Canada, Mem. 163.

Ziegler, W.H. 1969. The development of sedimentary basins in western and Arctic Canada. Alberta. Society of Petroleum Geologists.

Appendices

Appendix One

Paleomagnetic Data

Table 1 Station 9-Highway 22 Section

	AF = 0 Oe				AF = 50 Oe				AF = 100 Oe				AF = 150 Oe				AF = 200 Oe				AF = 250 Oe				AF = 300 Oe			
Smpl no.	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M
03AA1	52	45	5	46	49	46	6	24	15	36	13	16	7	23	21	14	355	21	16	10	346	30	19	13	12	13	26	9
03AA2	77	44	4	28	89	40	6	15	94	39	24	6	76	72	56	3	56	28	84	2	152	48	33	3	50	28	53	2
03AA3	86	54	7	32	57	59	12	12	332	36	46	7	326	13	26	9	317	32	25	9	324	25	16	13	306	15	22	8
03AC1	50	35	12	9.5	70	-9	16	6	70	-45	13	6.7	78	-61	11	5.5												
03AC2	56	29	10	10	52	-2	16	6.6	60	-39	15	6	62	-64	10	7												
03AD1	178	-75	28	33	127	-66	35	7	132	-24	17	1.8	134	-21	19	2.1												
03AD2	36	44	21	4.5	47	18	34	1.4	112	-44	28	1.3	122	-75	13	3												
03AD3	70	40	15	2	127	-13	46	1	150	-39	16	1.8	141	-49	19	2.2												
03AE1	41	63	7	11	36	62	16	4.2	354	28	22	1.9	237	83	54	1.2												
03AE2	55	43	6	11	57	24	11	4.6	68	-3	20	2.3	62	-27	20	2												
03AE3	67	60	10	10	75	42	17	3.5	48	2.8	32	1.1	15	-43	36	1.3												
03AG1	153	40	9	25	177	40	43	27.1	160	33	7	32	160	34	8	31	157	31	10	31								
03AG3	359	48	44	14	350	52	53	14	350	52	60	14	351	48	71	13.4	346	48	67	13								
03AH1	115	70	5	26.3	88	56	11	7.5	267	-71	34	4.2	274	-60	21	7.8												
03AH2	57	57	6.5	21.3	112	36	20	5.1	132	-77	16	4.3	177	-64	11	6.9												
03AH3	80	77	5.6	30.1	66	58	5.5	13.1	94	11	35	3.9	124	-61	35	3.9												
03AI1	70	16	13	13	49	-14	18	7	44	-43	14	7	12	-66	15	6.7												
03AI2	65	36	6	18	69	13	12	9.4	64	-23	28	4.8	51	-41	25	4.9												
03AI3	34	48	7	14	46	24	10	8	52	-11	14	6.5	46	-36	16	4.5												
03AJ1	122	9	9	10.9	136	-13	12	6.1	177	-45	13	5.7	196	-52	12	6												
03AJ2	108	16	12.5	12.3	133	-4	16	6.5	158	-31	13	6.1	179	-41	16	6.2												
03AJ3	127	61	12	7.2	153	33	19	3.9	179	-18	19	3.2	197	-28	21	3.9												
03AK1	66	40	7	14	87	34	8	7.8	105	17	13	4.5	129	-12	26	3.1												
03AK2	100	42	5.7	29.3	110	41	6	15.2	135	29	9	7.8	158	15	15	4.7												
03AK3	71	40	5	16.7	85	22	8	82	102	-15	13	5.1	123	-43	15	4.7												
03AL1	102	61	17	5.5	102	31	17	2.8	95	-17	20	2	93	-46	24	1.9												
03AL2	54	56	23	2.3	51	8	90	0.7	161	-64	73	1.2	176	-48	26	1.9												
03AL3	136	27	15	3.3	119	-5	33	2.3	129	-26	25	2.2	136	-51	17	2.7												

	AF = 0 Oe				AF = 50 Oe				AF = 100 Oe				AF = 150 Oe				AF = 200 Oe			
Sampling	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M
03AM1	63	48	24	3	34	31	61	4.3	79	25	30	1.6	76	-12	47	1.3	80	40	90	1
03AM2	45	49	23	3.2					66	37	34	2	60	22	37	1.4	32	21	60	1
03AM3	63	-5	11	6.2	65	-9	9	5.8	62	-18	12	5.5	61	-21	10	5.1	62	-25	14	4
03AN1	141	14	90	3.2	134	-31	15	3.7	140	-50	15	4	139	-56	16	4.1				
03AN2	127	11	21	3.8	134	-28	15	4.8	147	-51	13	5.3	150	-55	12	5.4				
03AN3	120	49	17	3.9	121	-3	17	3.2	127	-25	17	3.1	128	-35	20	3.1				
03AO1	16	16	49	1.4	310	-76	34	2	287	-63	12	4.1	287	-71	11	4.4				
03AO2	135	44	26	6.1	263	-54	15	4.4	283	-21	14	5.2	249	-55	31	3.9				
03AO3	2	41	16	4.8	329	-36	33	4.3	309	-24	16	4.7	313	-29	15	5				
03AP1	90	-52	31	2	89	-43	49	1.3	111	-78	29	1.7	190	-78	24	2.1				
03AP2	8	-30	11	5.8	2.6	-40	14	5.4	360	-48	11	4.9	357	-48	14	5.1				
03AP3	100	1	30	2.4	134	-39	31	2.2	171	-55	26	2.4	176	-52	18	3				
03AQ1	12	53	33	7	34	31	60	4.3	27	-4	90	3.4	27	-14	90	2.9				
03AQ2	33	36	33	7	34	14	63	4	27	-11	90	2.5	44	-27	90	2.2				
03AQ3	60	53	33	7	62	43	90	3	49	27	90	1.1	21	-21	90	0.8				
03AR1	34	44	90	3.1	25	21	90	2.6	14	7.5	90	1.7	9	0.5	90	1.8	9	1	90	1
03AR2	91	59	90	3.4	89	47	90	2.3	89	22	90	1.9	79	40	90	1.2	88	57	90	1
03AR3	32	27	90	3.4	34	13	90	3.2	43	4.6	90	3.1	42	-7	90	2.7	39	-24	90	3
03AS1	77	-8	90	3.2	99	-55	54	4.2	89	-75	52	4.4	76	-61	44	4.8				
03AS2	99	41	90	3.2	131	-43	90	2.2	140	-61	90	3	145	-62	90	2.9				
03AS3	112	28	36	5.9	139	-26	90	3.4	172	-45	90	3.4	179	-57	56	4				
03AT1	310	41	9	33	337	-54	42	6.2	297	-81	21	12	225	-83	18	16				
03AT2	123	55	8	30	84	24	16	14	102	-34	23	9.8	95	-58	20	11				
03AT3	84	80	9	30	42	-10	41	6.2	27	-65	23	10	56	-75	24	11				
03AU1	87	39	22	12	126	-43	33	6.4	143	-69	34	7	159	-72	23	8.8				
03AU2	78	40	20	11	3	-78	22	8.7	306	-83	17	13	16	-83	15	16				
03AU3	104	22	30	7.3	133	-51	19	9.8	136	-68	18	11	150	-68	17	11				
03AV1	43	68	7	36	50	64	9	25	48	64	13	16	45	60	19	11				
03AV2	33	51	16	14	37	44	21	11	35	35	27	8	35	23	44	5				
03AV3	34	58	19	13	36	45	23	9.5	36	35	31	6.6	25	24	46	4.6				

Table 2 Station 10 – Highway 22 Section (12Km south from the St.9)																								
	AF = 0				AF = 50				AF = 100				AF = 150				AF = 200				AF = 250			
Smpl no.	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M
St10A1	20	61	7	25	31	65	6	13.7	25	64	13	8.4	26	71	15	7	347	72	11	7.5	8	63	22	5.9
St10A2	42	-37	14	23	34	-8	20	11.5	14	30	22	6.4	359	29	39	3.8	350	46	13	6.9	341	48	16	6.9
St10A3	15	78	5	25.8	17	69	12	13.5	9	53	13	7	21	50	23	4.6	355	48	34	3.3	332	67	29	3.6
St10B1	349	46	27	5.5	279	52	36	5.6	291	13	18	5	293	42	26	6.5								
St10B2	56	36	47	5.8	46	17	17	4.5	50	52	11	6.3	54	54	20	4.9								
St10B3	42	35	26	5.2	25	2	90	1.99	350	41	19	4.3	357	10	22	4								
St10C1	336	29	30	4.5	5	41	23	6	344	50	23	6.8	307	46	24	5.8								
St10C2	49	44	39	6.5	2	47	34	6.1	318	46	36	4.6	328	21	21	6.3								
St10C3	5	38	24	5.9	328	39	32	6.7	329	35	46	4.8	332	61	22	6.4								
St10E1	15	47	9	57	351	57	9	35.3	325	58	11	26	323	51	11	26.4	331	45	10	30				
St10E2	356	49	5	72.7	345	45	7	36.6	320	36	14	28.9	320	20	13	30.9	316	25	19	25				

Table 3 Station 14- Oldman River-Maycroft Section

	AF = 0				AF = 50				AF = 100				AF = 150			
Smpl no.	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M
14L1	126	0.4	18	3	137	-32	20	2.8	129	-48	14	3.1	125	-47	29	2.9
14L2	214	-66	10	2.6	220	-68	10	3.8	205	-66	15	4.4	196	-66	12	3.4
14L3					105	-71	12	4.6	105	-80	8.7	4.8	108	-82	8	4.7
14A1	96	-68	36	3.6	125	-57	23	3.6	116	-61	25	2.8	236	-74	90	1.2
14A2	111	-79	55	2.4	150	-59	14	6.5	157	-55	24	6.6	461	-57	31	4.3
14A3	214	-76	90	2.3	64	-89	18	3.5	140	-81	53	1.99	192	-69	39	3.1
14B1	116	71	90	1.9	153	60	90	1.6	127	40	90	1.5	96	18	90	1
14B2	85	-42	34	4.5	88	-26	53	4	87	-29	60	3.5	79	-19	90	2
14B3	65	11	45	3.4	80	-5	90	2	53	1	90	2.3	53	7.8	90	2
14C1	34	4	90	1.3	56	-16	90	0.4	106	-10	90	0.38	99	-17	90	1.7
14C2	124	19	90	0.6	341	-21	90	0.4	77	10	90	0.09	241	54	90	0.7
14C3	157	4	90	0.4	194	35	90	0.3	127	-6	90	0.6	196	-46	90	0.3
14D1	163	-52	90	2.4	169	-58	90	0.9	131	-30	90	1.5	81	-34	90	0.4
14D2	145	-48	90	2.5	178	-16	90	2.3	184	-30	90	2.5	165	-21	54	3.4
14D3	271	79	90	2.5	221	48	90	1.4					236	30	90	2
14E.1	231	-85	26	6.4	170	-63	90	4.7	180	-48	49	3.8	268	-73	70	3.3
14E.2	63	21	26	6.4	51	11	51	5.8	47	10	59	4.3	73	16	90	4.3
14E.3	52	14	59	4.6	48	2.8	31	7.7	62	0.7	58	4	239	2.5	90	1.5
14F1	165	-49	21	17.2	158	-58	27	4.8	181	-52	23	13.3	177	-52	23	19
14F2	158	-59	9	22.7	153	-60	55	6.9	164	-56	18	17.9	160	-64	12	26
14F3	163	-67	15	8.2	143	-58	38	3.3	147	-62	26	10	148	-61	26	12
14G1	102	-4.5	28	2.5	123	-48	22	2.6	147	-72	16	3.5	185	-64	13	3.5
14G2	90	-5	19	2.2	126	-36	21	2.3	161	-42	19	3.2	168	-56	20	3
14G3	85	2.3	9	5.3	87	-7	10	3.5	95	-28	34	2.2	77	-56	22	2.6
14H1	33	52	11	20.1	36	40	9	15.2	34	33	9	12.1	48	30	12	9.7
14H2	122	-70	24	6.5	67	-62	32	3	47	-40	75	2.2	16	-46	74	1.8
14H3	324	-54	74	1.7	291	-78	53	2.1	255	-77	30	3.5	285	-71	21.7	4.1
14I1	76	21	12	29.4	45	-5	18	9.6	24	24	12	10.3	28	23.6	11	9.1
14I2	44	55	5	16.5	24	52	6.5	13.1	18	50	5	11	14	46	6.2	6.4
14I3	30	-25	22	12.7	29	-14	15	10.3	18	8	8	7.5	19	15	13	6
14J1	48	14	21	2.7	47	35	36	1.3	33	22	50	1.4	50	-0.3	80	0.89
14J2	30	31	31	1.99	358	41	51	1.1	350	33	43	0.8	346	22	90	0.69
14J3	4	72	21	3.8	18	63	13	3.8	32	82	17	3.1	21	83	18	2.7
14K1	330	40	21	23.3	342	11	14	20.1	341	11	19	18	342	11	16	15.5
14K2	7	65	10	25.1	343	67	11	19	345	55	8	16.5	350	51	12	14.7
14K3	319	52	10	33.6	316	41	15	22.8	309	37	14	21	314	36	16	20
14M1	241	74	7	12.2	252	68	4	11.8	268	67	5	11.6	264	66	6	10.7
14M2	230	50	5	12.6	231	42	5	11.3	237	35	6	10.9	238	35	7	10
14M3	276	68	5	26.8	278	67	5	26.1	277	68	4	25.2	276	68	5	25

Table 4 Station 28-Oldman River Dam Reservoir-Crowsnest River section

	AF = 0 Oerstd				AF = 50 Oerstd				AF = 100 Oerstd				AF = 150 Oerstd				AF = 200 Oerstd				Thermal = 200 dc				Thermal = 250 dc				Thermal = 300 dc			
Smpl no.	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M
ST28D1	231	48	90	2	243	48	37	2	223	-73	90	1.7	224	-59	30	1.5	218	-40	81	0.8	184	-52	20	1.4	178	-81	41	1.4	210	-70	39	1.2
ST28D2	182	-28	90	1	167	-61	53	2	170	51	70	2.2	159	-55	27	2	189	-57	15	1.8	152	-55	12	2.4	143	-61	36	1.8	173	-63	43	1.5
ST28D3	215	64	90	1	225	58	90	1	211	-9	90	1.2	146	-57	34	1.2	159	-61	29	1.4	125	-75	30	1.4	133	-76	48	1.5	122	-70	44	1.2
ST28A1	119	75	33	8	127	74	31	8	307	37	28	8.5	305	-56	16	1.7	316	-65	37	2.4	313	-66	23	3.1	307	-61	16	2.7	64	-79	34	1.8
ST28A2	6	51	61	4	30	60	53	4	141	35	28	5.8	111	-60	17	2.7	161	-64	17	3.5	154	-65	26	2.9	125	-64	10	4	143	-66	16	3.7
ST28A3	107	13	40	3	96	11	48	2	100	71	32	7.5	154	-71	31	1.8	100	-68	29	1.6	289	-89	27	2.1	148	-73	21	2.3	149	-62	19	2.2
ST28B1	346	71	17	17	354	71	10	15	44	38	90	3.6	341	-32	25	2	322	-45	16	2.4	314	-50	15	2.5	325	-38	18	2.3				
ST28B2	255	-69	30	9	264	-76	27	5	229	19	34	5.9	332	-74	18	3.1	339	-72	14	3.5	343	-76	17	3.4	319	-72	14	3.6				
ST28B3	35	-22	90	0.7	128	15	90	0.2	31	-78	48	4.4	113	-69	19	3.2	123	-61	25	2.3	129	-64	19	2.7	121	-53	31	2.2				
ST28C1	45	77	16	3	48	73	11	3	226	13	35	2.9	257	3.6	14	2.7	238	7	20	2.9	316	15	77	1.2	281	-4	19	1.9				
ST28C2	373	67	27	2	27	53	30	2	126	-61	90	2.7	45	-71	16	3.1	80	-79	18	2.7	14	-74	20	2.5	3	-70	23	2.2				
ST28C3	369	63	11	5	35	66	17	3	30	55	12	9.3	46	-28	24	2.1	48	-24	32	1.9	32	-24	13	3	61	-25	11	3.5				
02MZ1	120	-38	16	8	118	-56	11	6	74	-70	31	7.9	44	-53	15	9.9																
02MZ2	323	-80	8	20	338	-81	8	19	119	-67	9	28	130	-71	12	23																
02MZ3	40	-41	10	19	38	-38	7	20	78	-69	10	27	76	-66	11	22																
02MY1	317	26	18	5	345	41	90	3	78	57	39	8.8	45	65	21	5	309	35	90	1.7	2.5	72	21	5.5	265	60	22	6.3	275	70	18	4.2
02MY2	253	41	28	7	258	34	28	7	27	85	31	8.7	293	71	20	4.4	166	44	32	3.4	184	50	90	1.6	190	75	23	6.5	206	26	27	4.5
02MY3	277	-4	7	33	283	-6	7	34	183	20	54	5.2	202	31	10	5	202	17	19	3.7	255	28	42	4	283	12	25	4.6	273	29	12	7.5
02MX1	141	-57	13	150	196	-81	4	71	142	-35	5	192	140	-35	5	186																
02MX2	41	-16	5	246	36	-20	10	236	55	-29	6	208	52	-27	4	192																
02MX3	29	-35	6	169	29	-36	6	171	20	-30	5	175	19	-35	23	148																
02MT1	186	63	17	22	171	64	21	17	182	7	19	15					168	9	23	5	284	45	90	3	58	32	47	4	52	37	28	8
02MT2	219	31	42	8	195	26	39	9	74	28	90	9.5	16	22	38	5.6	41	-2	54	4	7	16	61	6	43	29	82	4	47	72	20	12
02MT3	287	47	7	13					189	65	17	13	160	73	11	11	161	76	10	12	273	84	17	10	345	81	18	9	315	59	14	11
02MS1	342	40	43	14	327	33	23	14	288	8	17	26	313	19	13	13	300	14	7	14	317	21	14	13	313	21	16	19	338	-6.5	40	9
02MS2	50	-22	24	20	63	-21	39	9	6	-70	22	13	34	-38	61	5	338	-29	37	7.6	3	-6	36	13	334	-16	90	4.5	3	-17	22	15
02MS3	No Sample																															
02MW1	321	51	28	9	70	0.2	10	45	42	-10	16	25	41	-2	14	25																
02MW2	288	55	27	7	26	56	67	2	337	-20	27	10	312	-27	90	2.8																
02MW3	22	57	24	9	63	61	90	4	352	-4	20	14	2.6	-2	23	9.4																

	AF = 0 Oerstd				AF = 50 Oe				AF = 100 Oe				AF = 150 Oe				AF = 200 Oe				Thermal = 200 dc				Thermal = 250 dc				Thermal = 300 dc			
Smpl no.	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M
02MV1					334	59	4	85	345	61	6	67	317	39	5	38	320	41	5	39	322	38	7	46	320	41	8	41	321	35	5	37
02MV2	340	37	6	37	344	35	7	42	347	33	7	26	315	26	5	17	341	25	6.6	18	318	19	7	21	319	21	8	18	311	32	11	14
02MV3	306	56	16	54	314	49	4	59	309	46	22	35	298	31	7	27	298	30	6	26												
02OT1	95	61	3	207	27	85	27	175	63	63	8	125	15	62	4	87	3.1	61	5	76	355	54	4	83	353	48	9	72	347	41	8	73
02OT2	11	86	53	286	74	85	53	282	12	12	7	286	3	45	5	140	347	42	7.6	126	349	28	12	143	338	28	15	132	338	27	9.4	116
02OT3	341	87	2	195	103	72	2	195	55	68	10	211	50	66	4	221																
02OS1	233	-41	6	478	232	-44	6	470	38	45	5	398	33	45	7	363																
02OS2	194	-53	5	271	190	-74	41	232	53	45	4	299	64	58	33	-263																
02OS3	184	-51	11	327	160	-64	36	294	23	44	4	344	19	46	3	330																
02OR1	160	-67	16	252	167	-52	5	283	19	44	7	349	21	55	20	298																
02OR2	232	-47	3	623	235	-45	6	614	16	38	5	523	19	24	18	470																
02OR3	192	-54	4	308	188	-62	6	206	32	64	4	203	37	63	5	201																
02OQ1	8	50	10	451	9	50	9	431	76	86	2	266	353	51	6	153	345	52	16	104	323	38	13	128	343	34	25	112	325	29	17	123
02OQ2	15	35	12	41	17	33	15	45	28	55	12	36	6	53	5	20	12	49	6.2	15	354	55	15	10	344	35	22	9	3.2	23	9	13
02OQ3	37	48	6	260	37	49	4	256	40	40	4	274	24	40	16	256																
02PO1	243	-60	4	113	238	-61	8	102	62	57	10	75	90	65	26	69					50	53	10	44	41	53	10	36	39	63	13	24
02PO2	68	40	8	113	64	42	6	113	63	43	9	122	64	45	7	124					52	41	10	53	36	39	7	40	37	44	12	28
02PO3	51	60	7	68	42	60	10	68	37	58	9	67	41	55	8	69																
02PN1	58	74	3	109	47	69	6	90	47	71	7	72	48	74	8	67					2	56	13	41	4	60	24	30	337	47	36	21
02PN2	12	71	4	92					353	68	6	63	1	72	10	64					349	58	10	27	4	62	8	21	3	56	18	17
02PN3	30	60	31	45	16	49	65	37	13	70	17	26	2	71	17	27																
02PM1	337	13	59	6	328	29	58	6	148	-15	8	67	39	24	90	0.8																
02PM2	22	2	12	13	22	-16	26	12	51	-16	23	2.3	60	-14	35	3.5																
02PM3	357	18	62	14	352	36	13	18	22	63	26	2.6	340	59	15	8																
02QK1	242	-38	41	9	238	-26	36	9	36	42	10	20	43	45	9	22																
02QK2	129	52	90	1	10	-23	69	3	342	13	90	12	354	6	15	18																
02QK3	111	80	22	5	52	84	40	4	56	78	16	7.9	30	73	26	7.1																
02QJ1	219	57	13	133	240	62	31	120	217	63	14	143	228	62	4	147					230	59	8	45	213	59	19	26	248	14	19	24
02QJ2	341	66	10	70	335	65	17	70	7	59	11	74	13	51	6	80					356	42	8	31	350	20	10	27	345	17	9	19
02QJ3	238	57	14	146	228	51	13	156	221	66	12	158	235	64	4	160																

	AF = 0 Oerstd				AF = 50 Oe				AF = 100 Oe				AF = 150 Oe			
Smpl no.	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M
02SI1	80	54	7	196	69	52	7	197	48	53	31	176	67	51	13	183
02SI2	55	37	9	214	55	41	6	218	38	60	4	185	44	60	5	173
02SI3	95	48	43	210	105	34	41	219	83	53	31	176	67	51	13	183
02TH1	27	20	43	8	50	32	50	6	50	39	8	9	47	34	12	7
02TH2	19	46	26	15	23	28	34	8	21	60	76	17	20	36	11	28
02TH3	21	44	51	4	357	45	12	23	1	45	11	15	359	45	5	15
02VF1	347	62	90	5	334	34	31	6	2	47	13	7	7	46	11	8
02VF2	214	-78	53	4	255	-24	90	1	56	66	14	9	59	65	17	10
02VF3	232	86	90	3	218	-1	90	3	45	63	16	10	28	51	73	3
02WE1	31	33	9	21	33	30	10	25	32	32	18	7.5	27	18	16	12
02WE2	27	28	15	28	29	29	11	30	22	14	27	5.3	22	25	30	4.4
02WE3	53	73	16	17	40	71	16	15	90	69	65	3.6	49	75	28	3.7
02XD1	308	78	35	27	108	71	29	14	261	67	63	5.7	227	49	42	4.3
02XD2	8	67	31	37	356	78	11	43	359	64	8	22	2.4	67	11	19
02XD3	327	83	75	23	283	79	26	30	260	66	17	13	260	39	37	9.4
02YB1	279	-77	90	6	242	-66	90	3	99	-61	90	1.6	91	-82	14	4
02YB2	179	-2	56	6	173	-14	47	7	181	-23	90	0.6	94	-30	90	1
02YB3	332	-72	90	2	313	-59	90	1	240	5	90	0.6	75	-25	90	1.2
02YC1	330	32	90	0.6	88	-11	52	0.8	59	-38	90	0.6				
02YC2	313	-1	90	0.4	282	-46	90	0.8	87	68	90	0.4				
02YC3	266	-36	90	0.6	139	-13	58	0.9	172	-7	49	1.9				
02ZA1	48	40	8	49					45	26	12	18	40	31	9	23
02ZA2	200	50	38	4					97	62	32	4.1	24	86	38	4.6
02ZA3	156	84	30	9					157	76	33	7.6	156	83	31	9.2

Table 5 Station27-Castle River section																				
	AF = 0 Oe				AF = 50 Oe				AF = 100 Oe				AF = 150 Oerstd				AF = 200 Oerstd			
Smpl no.	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M	Dec	Inc	Theta	M
27A1	62	52	28	2.5	49	55	42	1.5	15	50	30	1.4								
27A2	102	82	39	2	357	82	32	19	260	82	35	1.88	186	76	43	1.8	190	58	40	1.5
27A3	307	56	16	4.8	310	49	19	3.6	313	52	18	3.4	320	33	12	3	318	31	21	2.7
27B1	355	45	5.6	14	5	56	9	8.9	7	46	8	5.8	337	51	23	5.3				
27B2	39	67	7	30	18	73	6	18.3	355	72	9	11.6	338	85	14	10.4				
27B3	16	46	7.6	18	357	45	8.7	11	350	40	17	8.4	344	29	11.5	8.6				
27C1	24	55	5.4	20.2	15	55	7.2	13	9	55	8	9.4	13	55	12	7.5				
27C2	51	61	3.8	16.1	20	67	7.2	11.2	7.6	71	9	8.6	352	57	12	7.3				
27C3	33	45	3	23.5	30	52	5.7	14.3	23	57	7	11	10	59	8.5	9				

Appendix Two

Change in magnetic behavior presented in Polar equal area net

Diagrams shown in the following pages are "polar projection equal area stereographic plots" of directional behavior during AF step demagnetization of samples from various sites of various sections.

Solid dots represent normal zones in lower hemisphere and open circles represent reverse zone in upper hemisphere.

One and two (0 and 15) digit numbers value in mT and three digit numbers (200 and 300) value in "degree celcius". Other two numbers are samples number and elevation of site, can be read from the vertical profile shown in the appendix two.

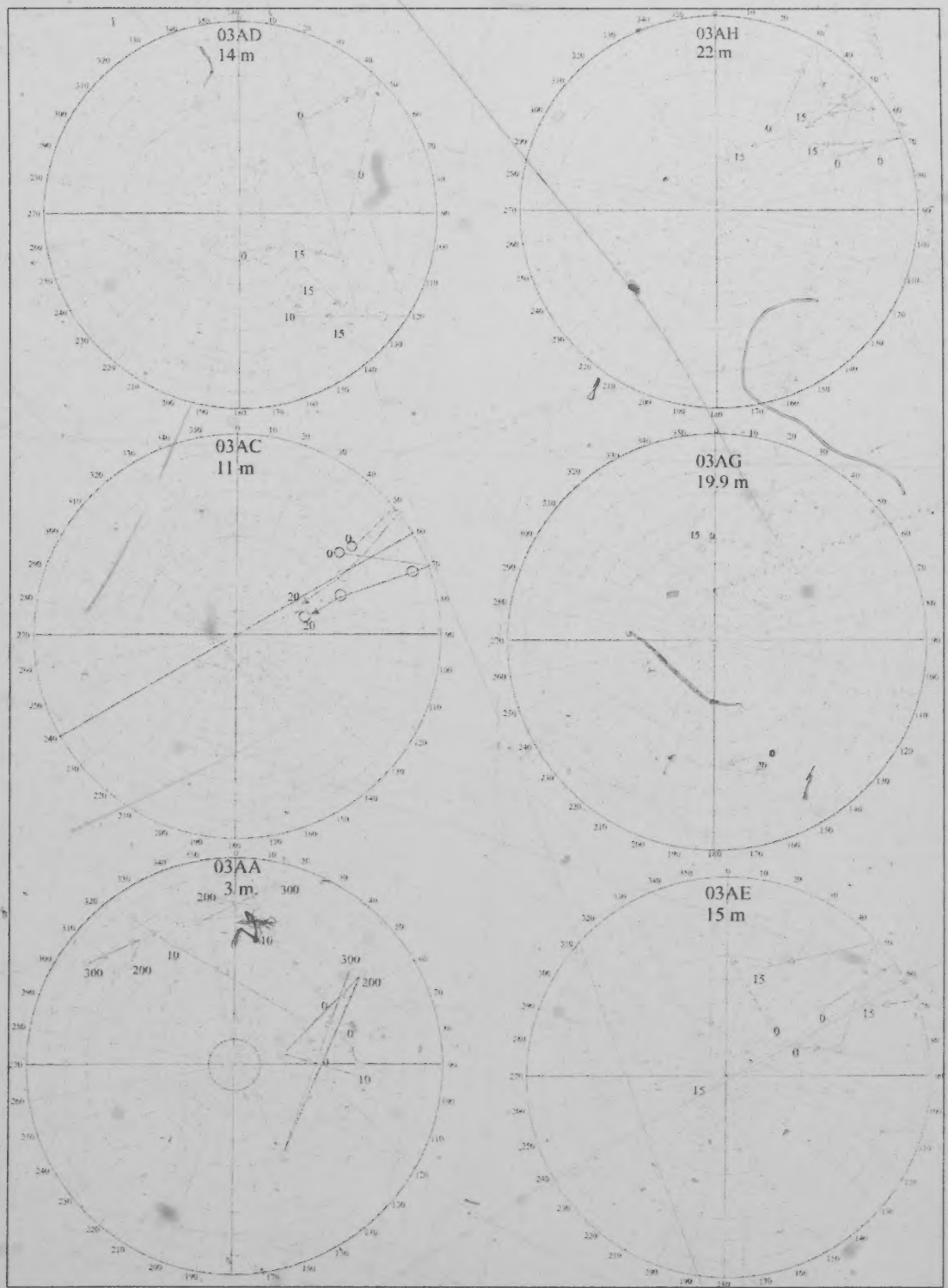

Figure A2.1 **Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Station 9-Highway 22 section I**

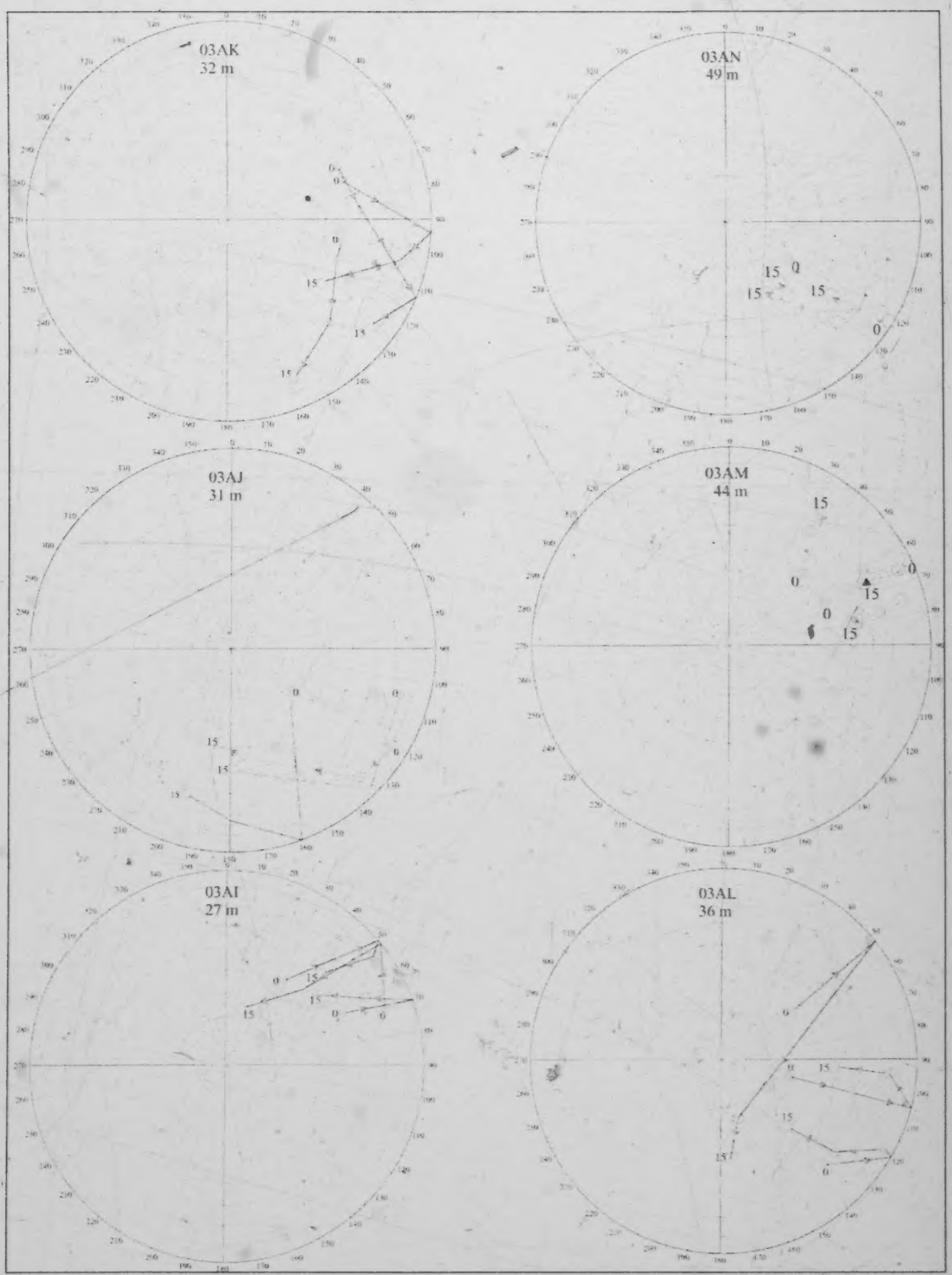

Figure A2.2 **Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Station 9-Highway 22 section II**

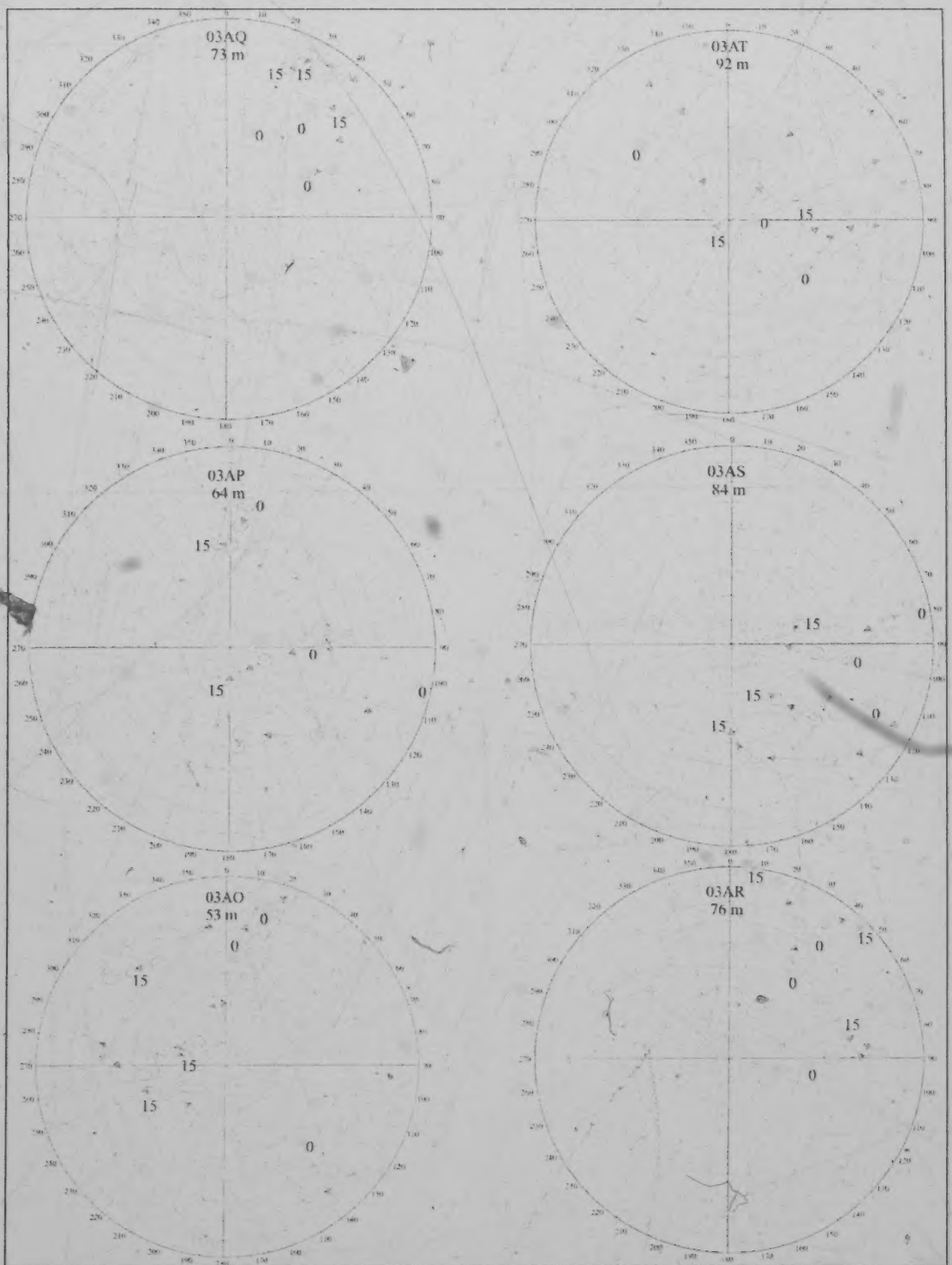

Figure A2.3 **Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Station 9-Highway 22 section III**

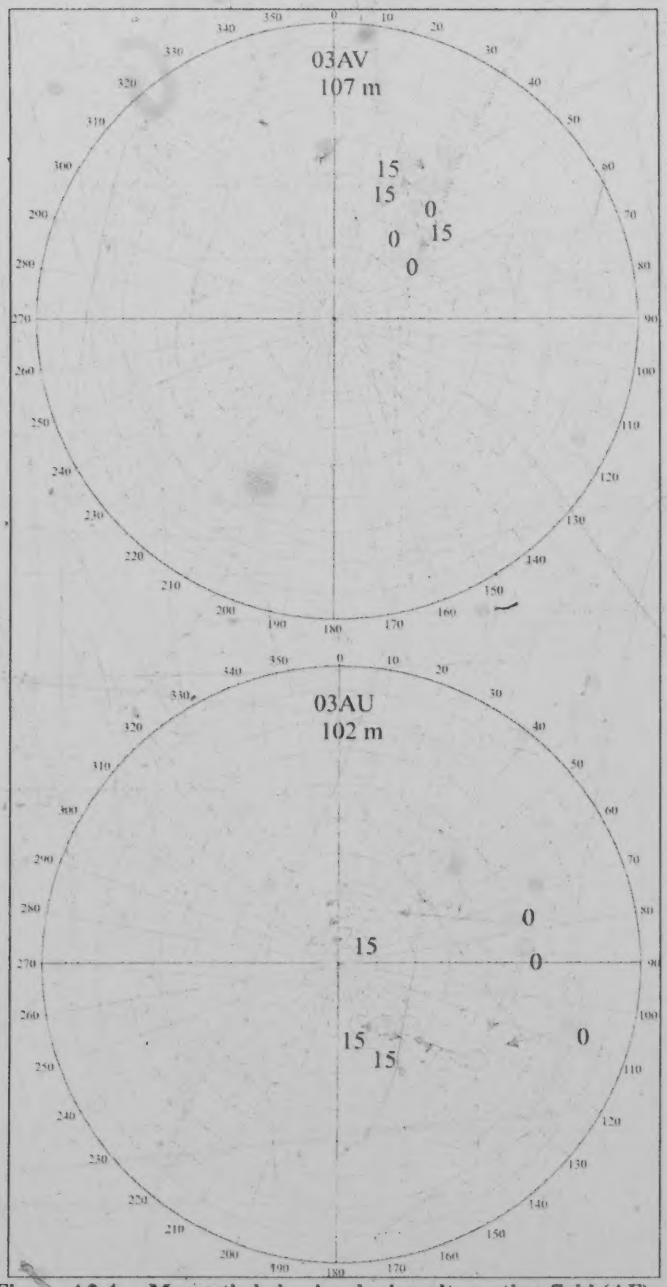

Figure A2.4 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Station 9- Highway 22 section IV

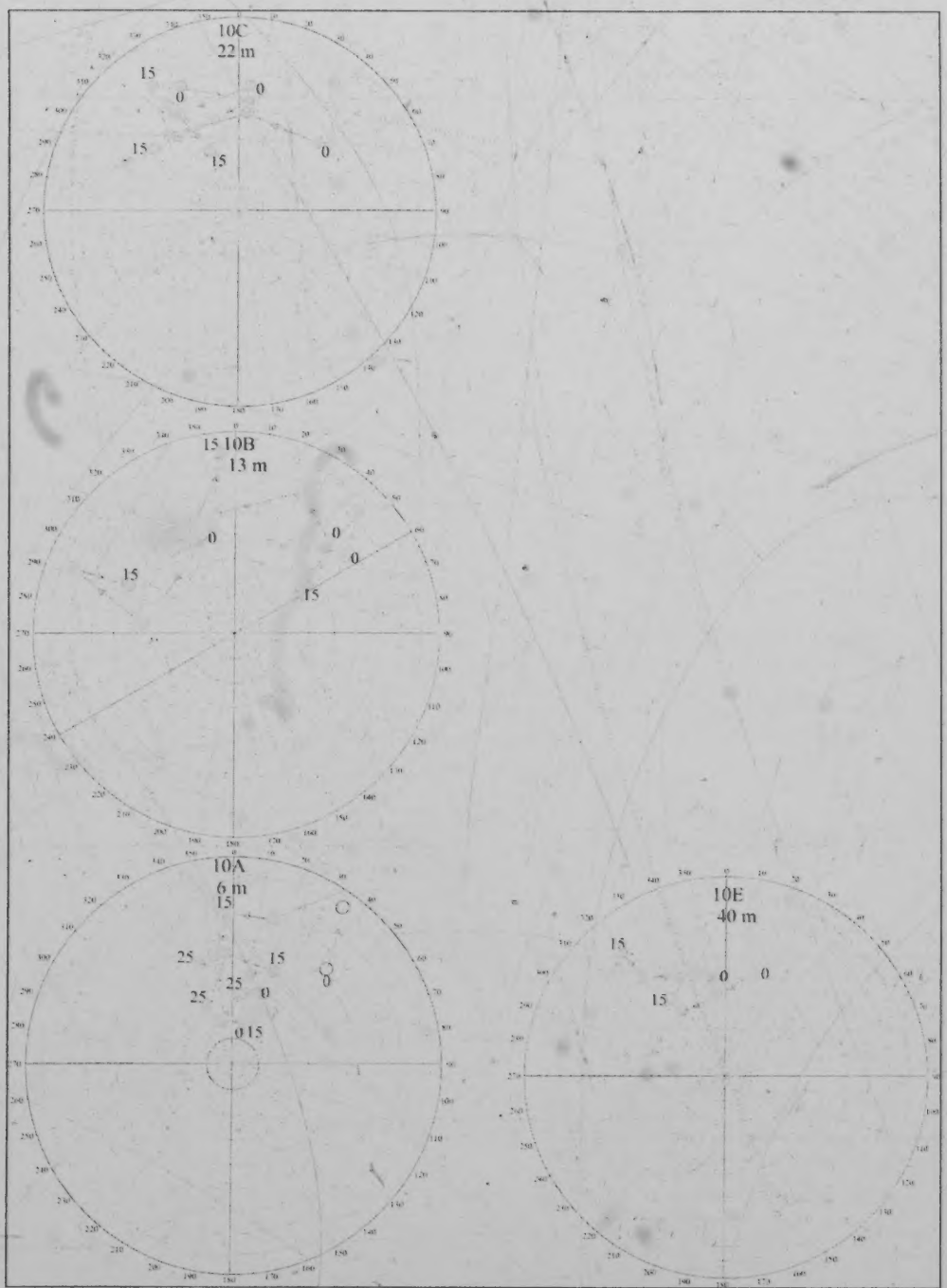

Figure A2.5 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Station 10-Highway 22 section

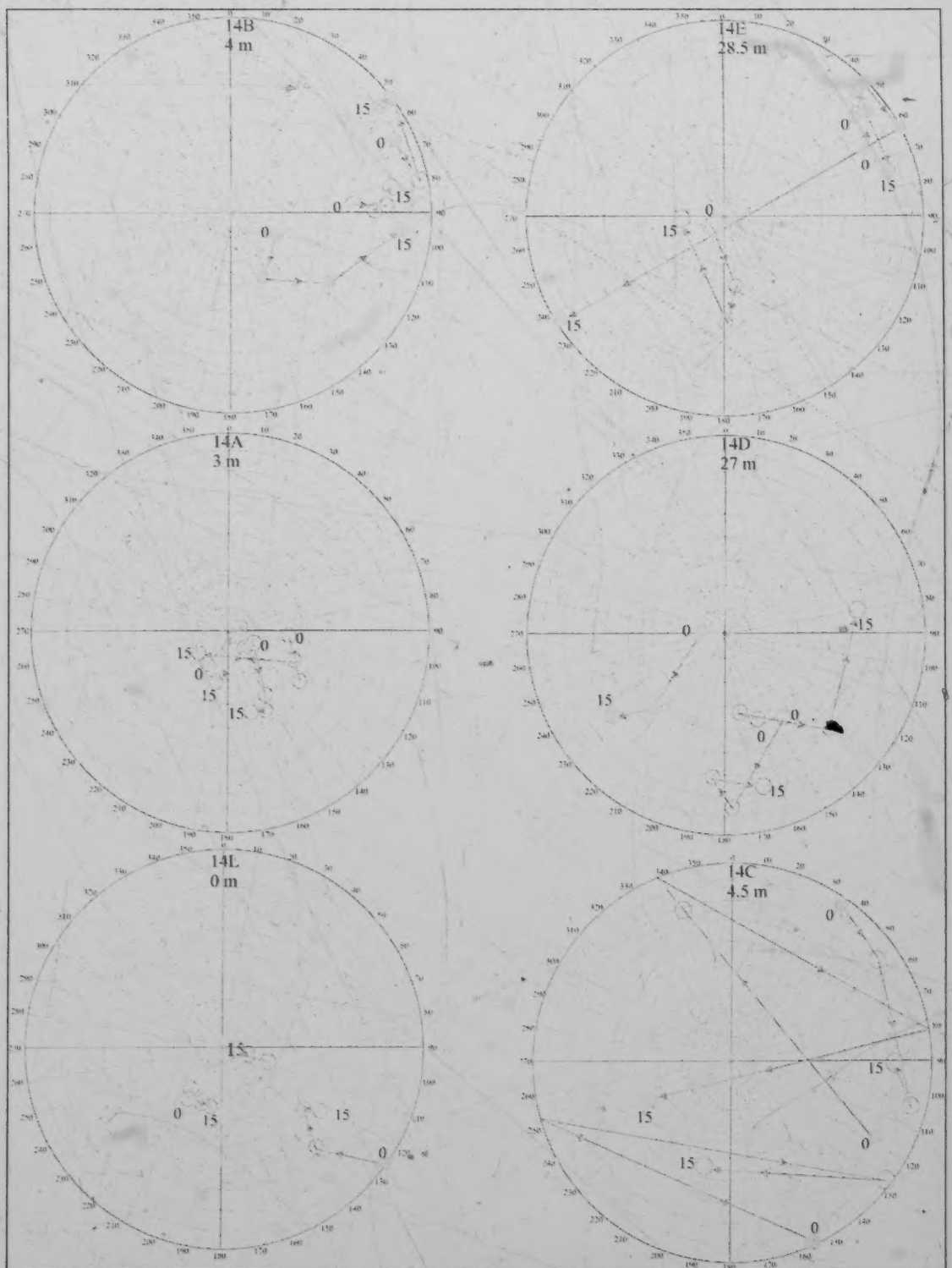

Figure A2.6 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites (Oldman River-Maycroft section).

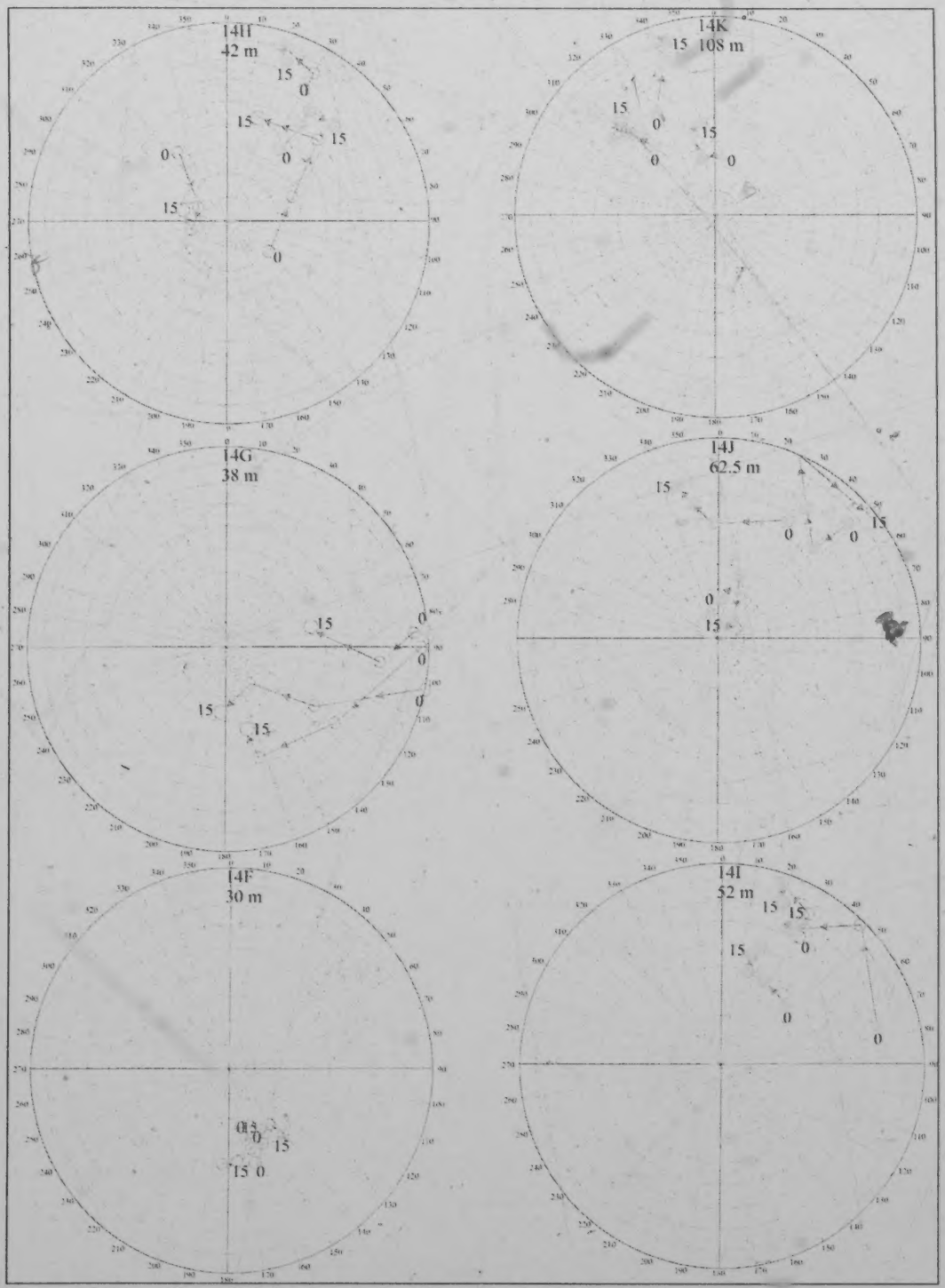

Figure A2.7 **Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Oldman River-Maycroft II**

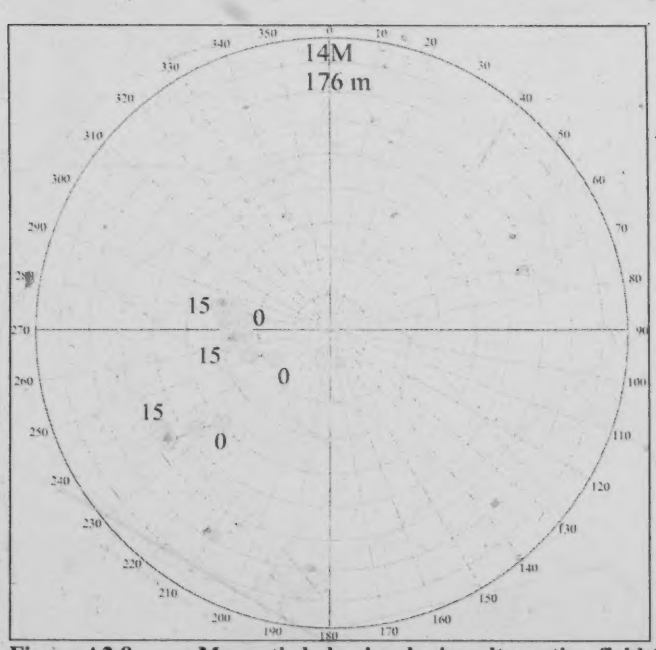

Figure A2.8 **Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Oldman River-Maycroft III.**

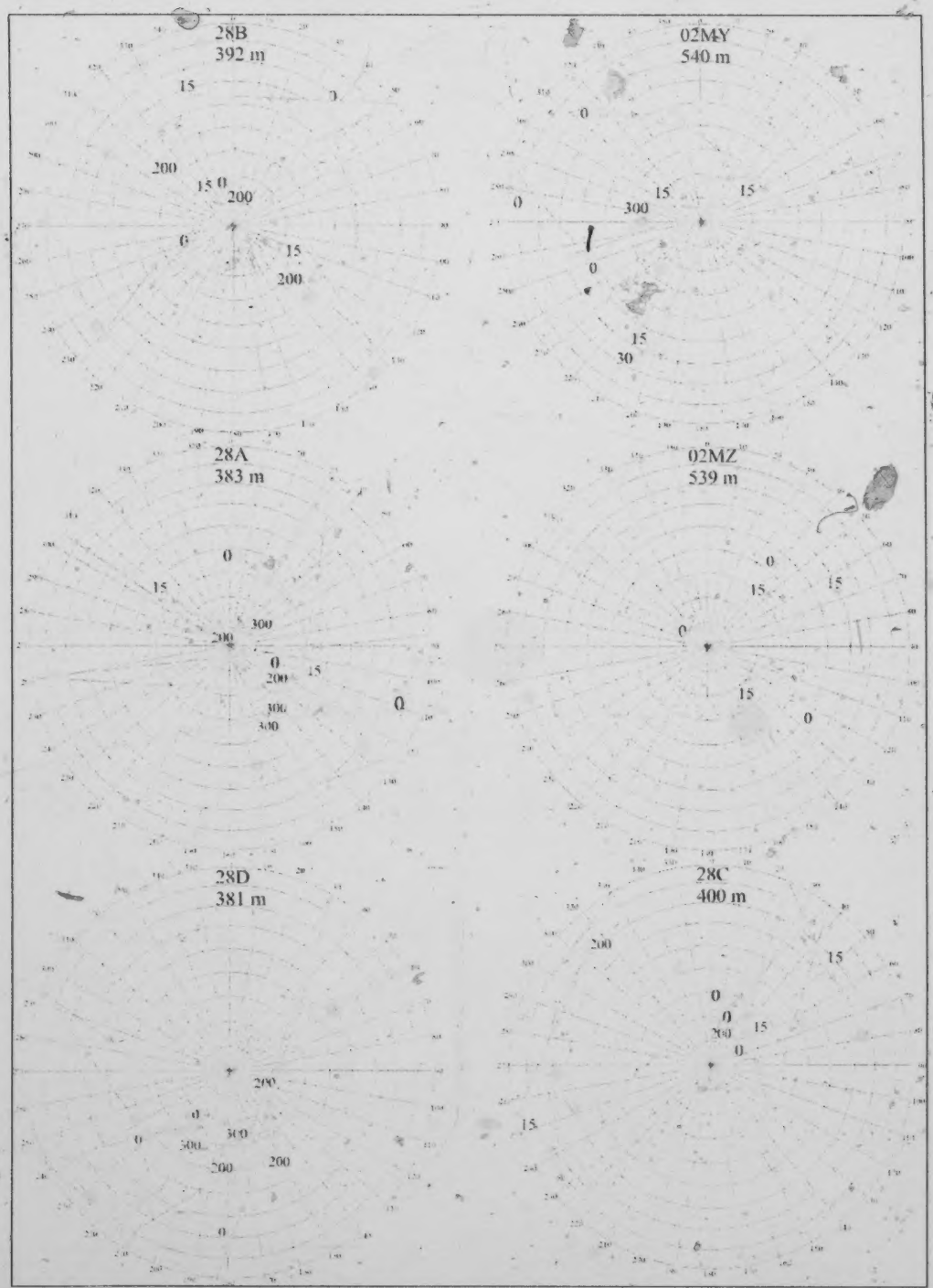

Figure A2.9 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Oldman River Dam Riservoir (ORDR) Crowsnest River Section I.

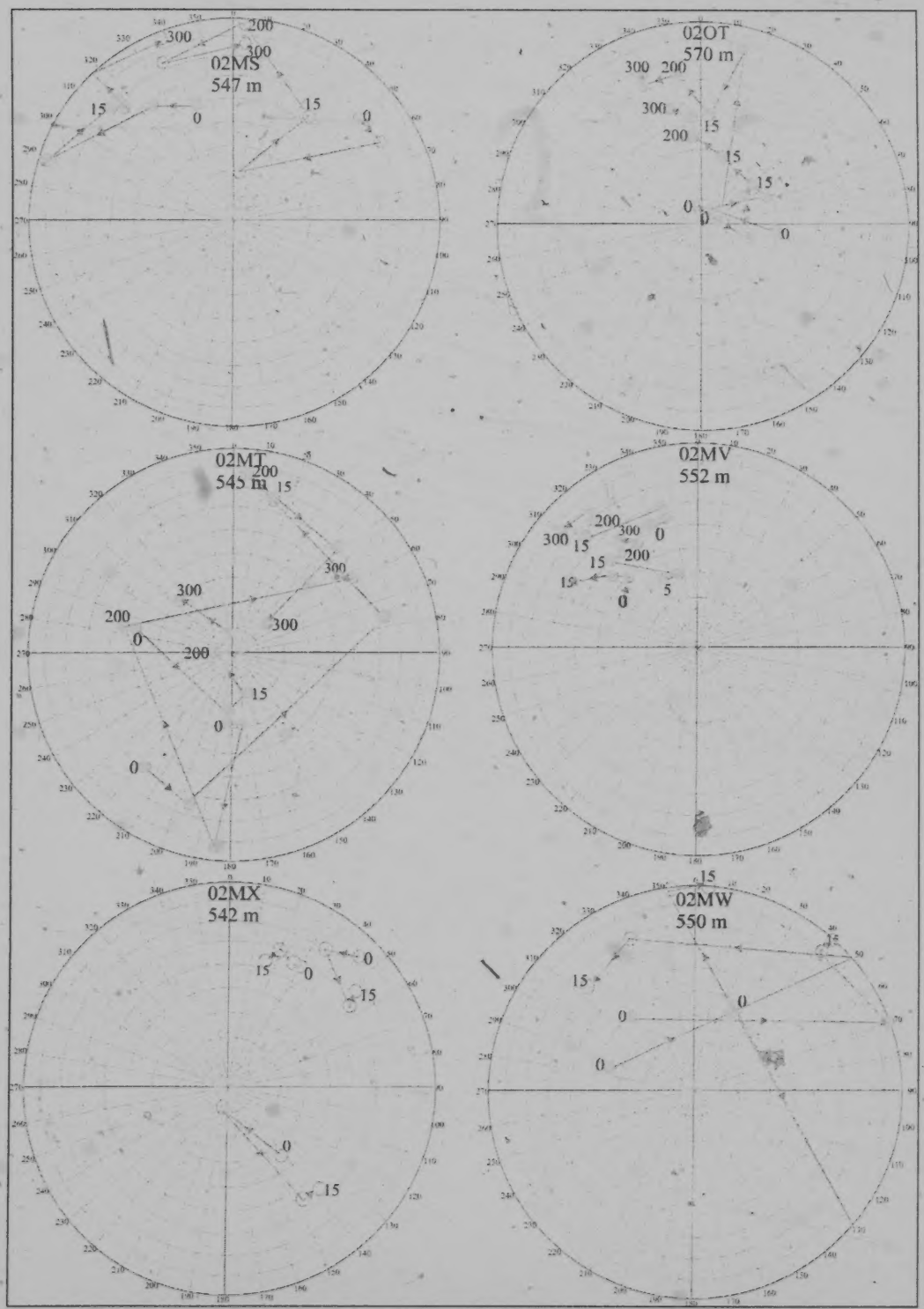

Figure A2.10 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Oldman River Dam Reservoir (ORDR) Crowsnest River Section II.

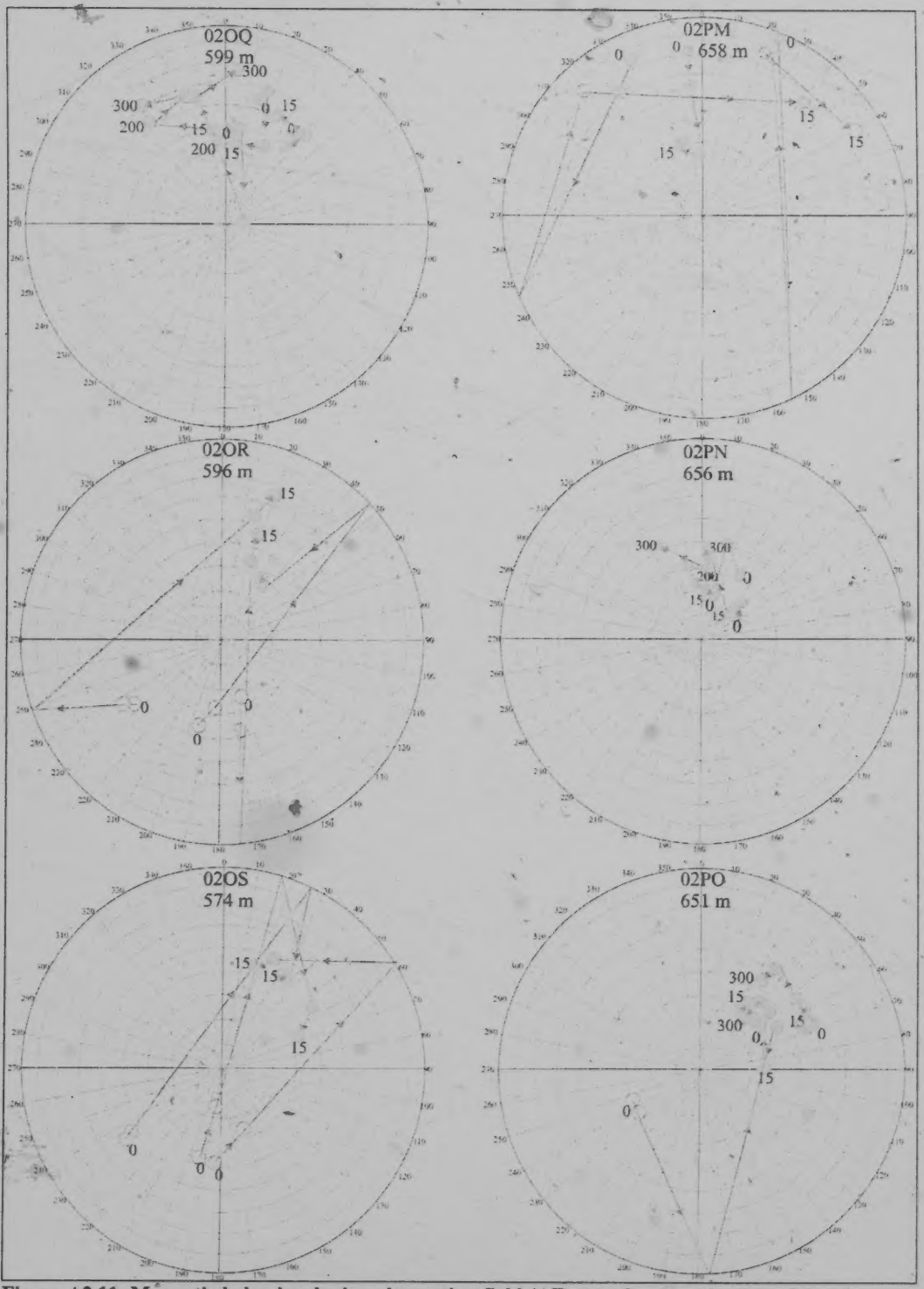

Figure A2.11 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Oldman River Dam Reservoir (ORDR) Crowsnest River Section III.

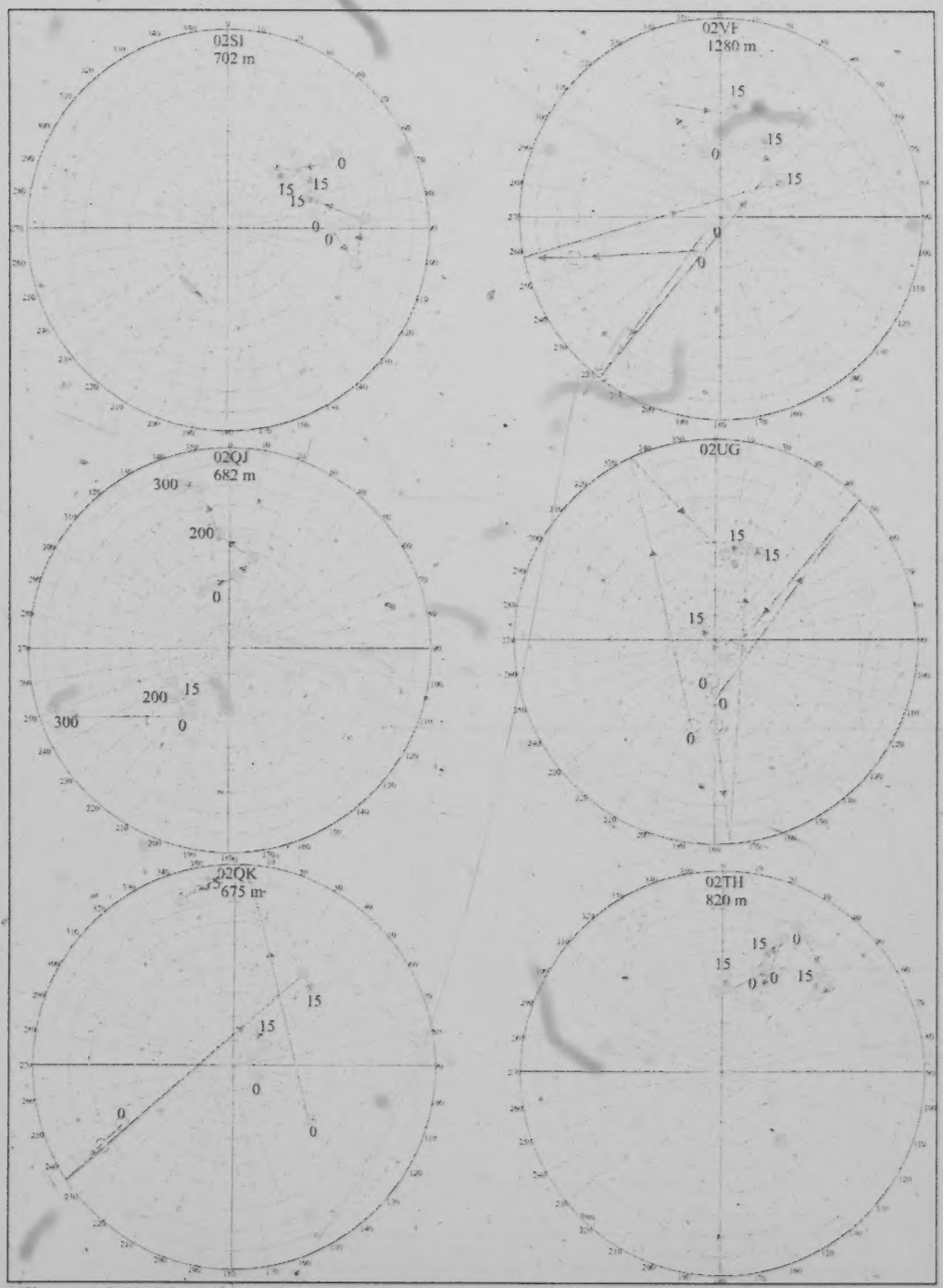

Figure A2.12 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Oldman River Dam Reservoir (ORDR) Crowsnest River Section IV.

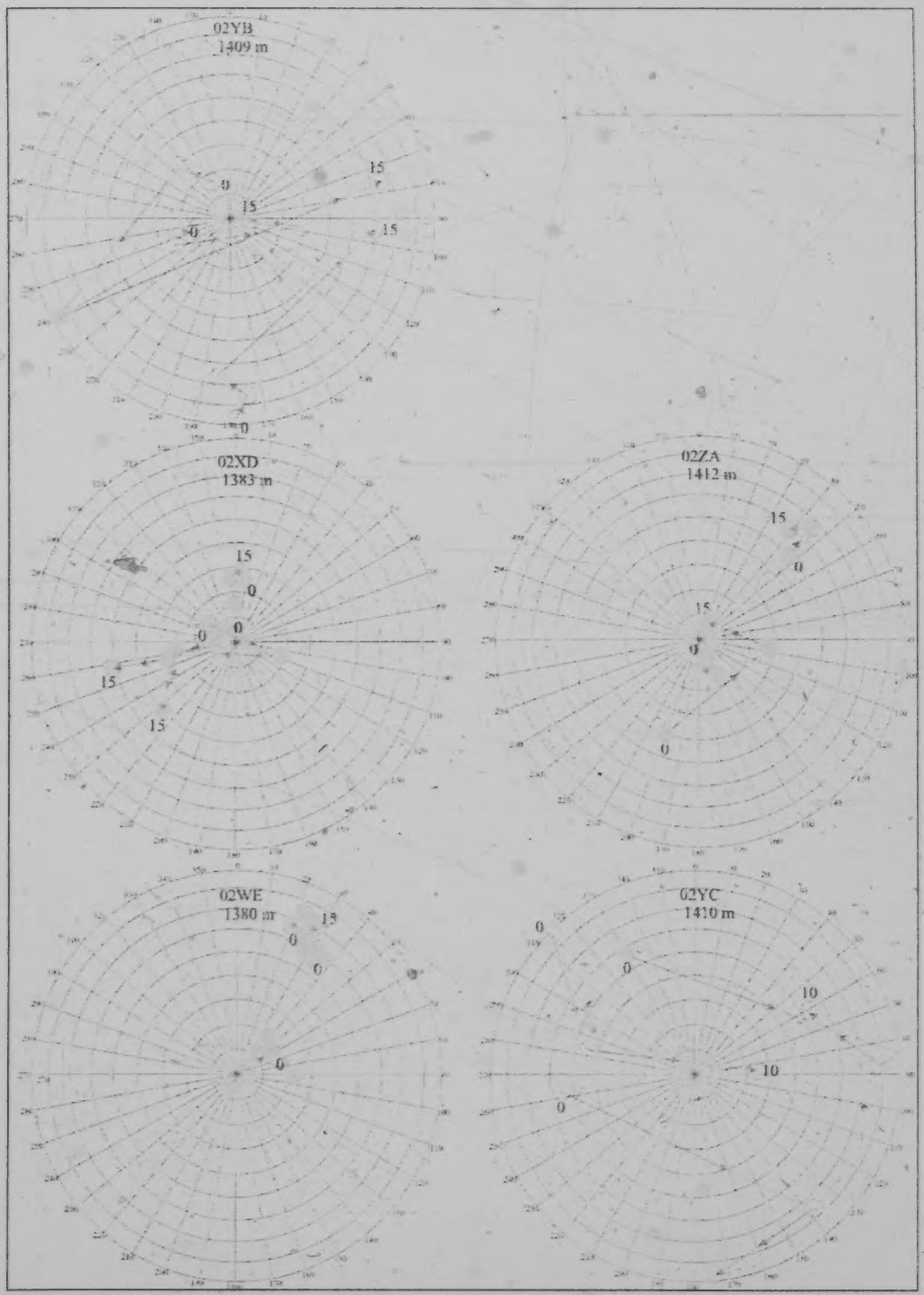

Figure A2.13 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Oldman River Dam Riservoir (ORDR) Crowsnest River Section V.

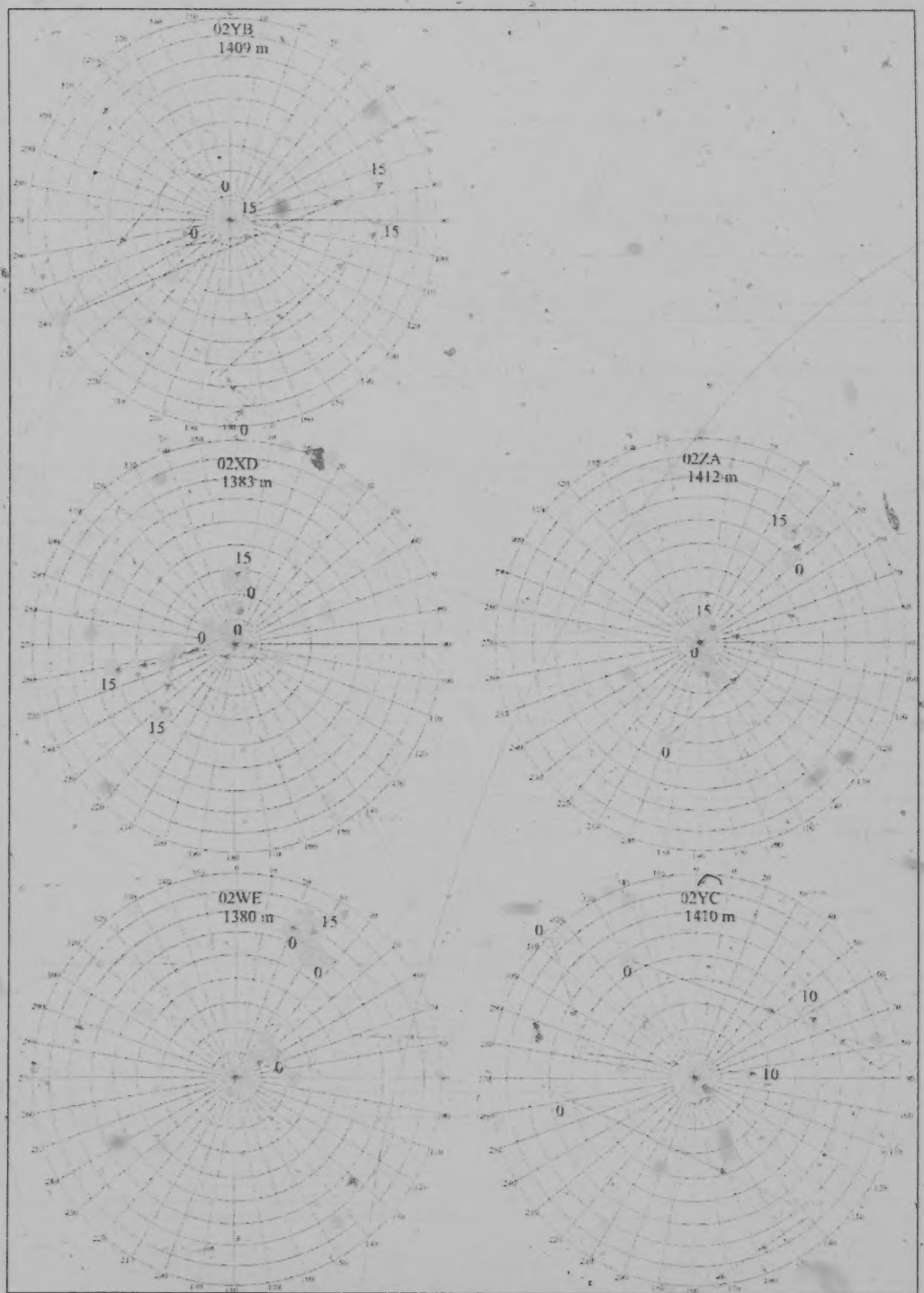

Figure A2.13 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Oldman River Dam Riservoir (ORDR) Crowsnest River Section V.

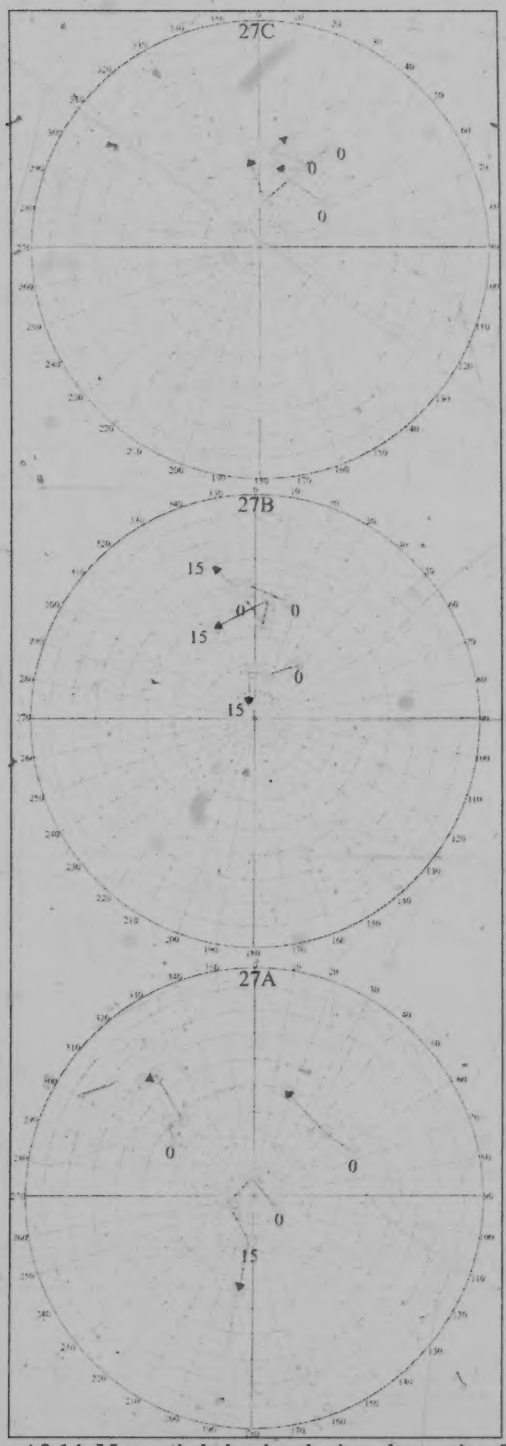

Figure A2.14 Magnetic behavior during alternating field (AF) step demagnetization of three samples from different sites of the Station 27-Castle River section.

Appendix Three

Maps, Airphoto, and Photographs

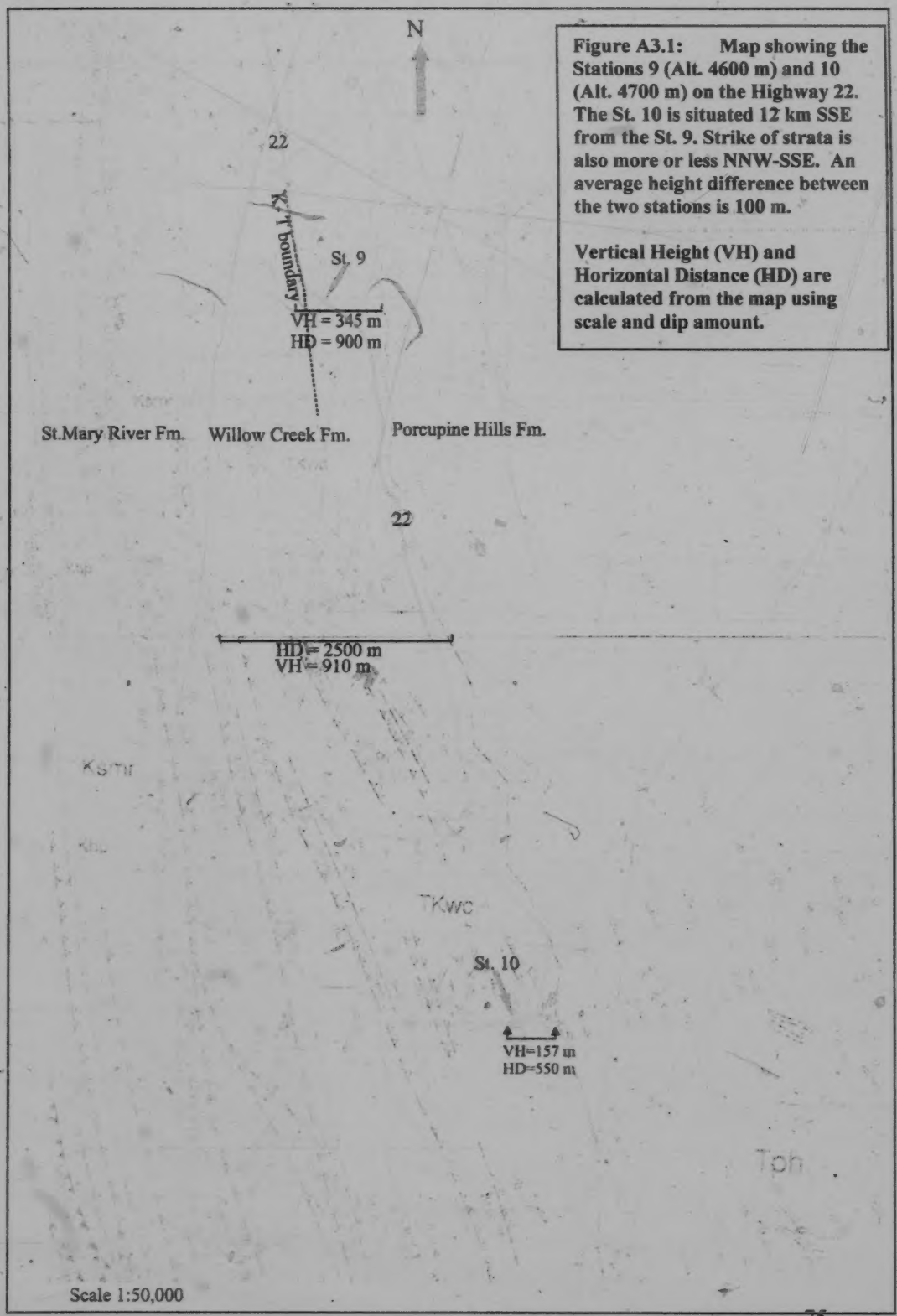

Figure A3.1: Map showing the Stations 9 (Alt. 4600 m) and 10 (Alt. 4700 m) on the Highway 22. The St. 10 is situated 12 km SSE from the St. 9. Strike of strata is also more or less NNW-SSE. An average height difference between the two stations is 100 m.

Vertical Height (VH) and Horizontal Distance (HD) are calculated from the map using scale and dip amount.

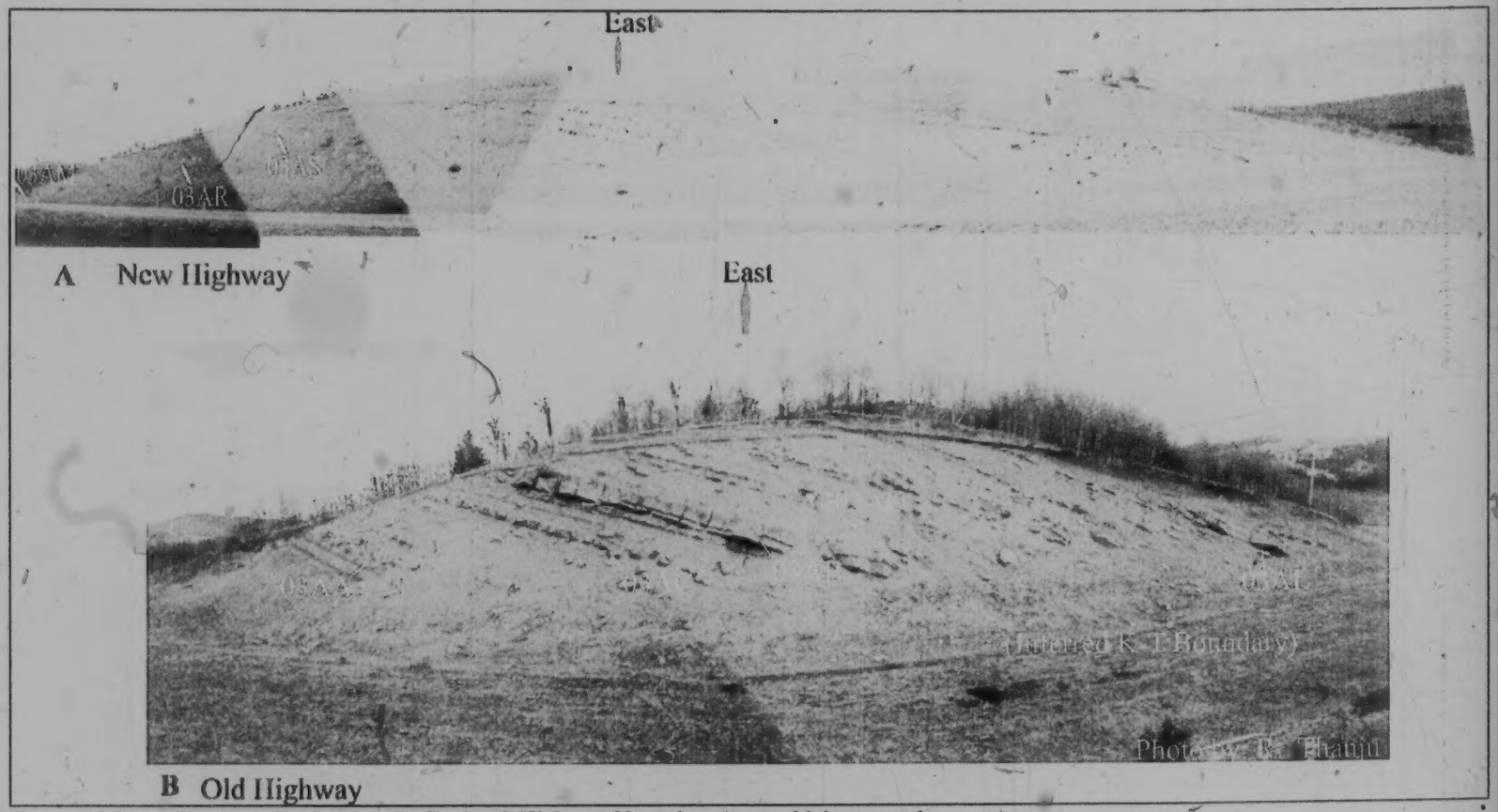

Figure A3.2 **Photographs showing the Station 9-Highway 22 section. A: new highway section of Paleocene deposits, B: old highway section of both Maestrichtian and Paleocene deposits.**

Figure A3.3 **Photograph showing Station 10-Highway 22 section. View of upper Willow Creek Formation and its boundary with Porcupine Hills Formation. The boundary is about 350 m (measured from the Map) horizontally away from the last exposure of Channel sandstone and the stratigraphic thickness is calculated to be 100m.**

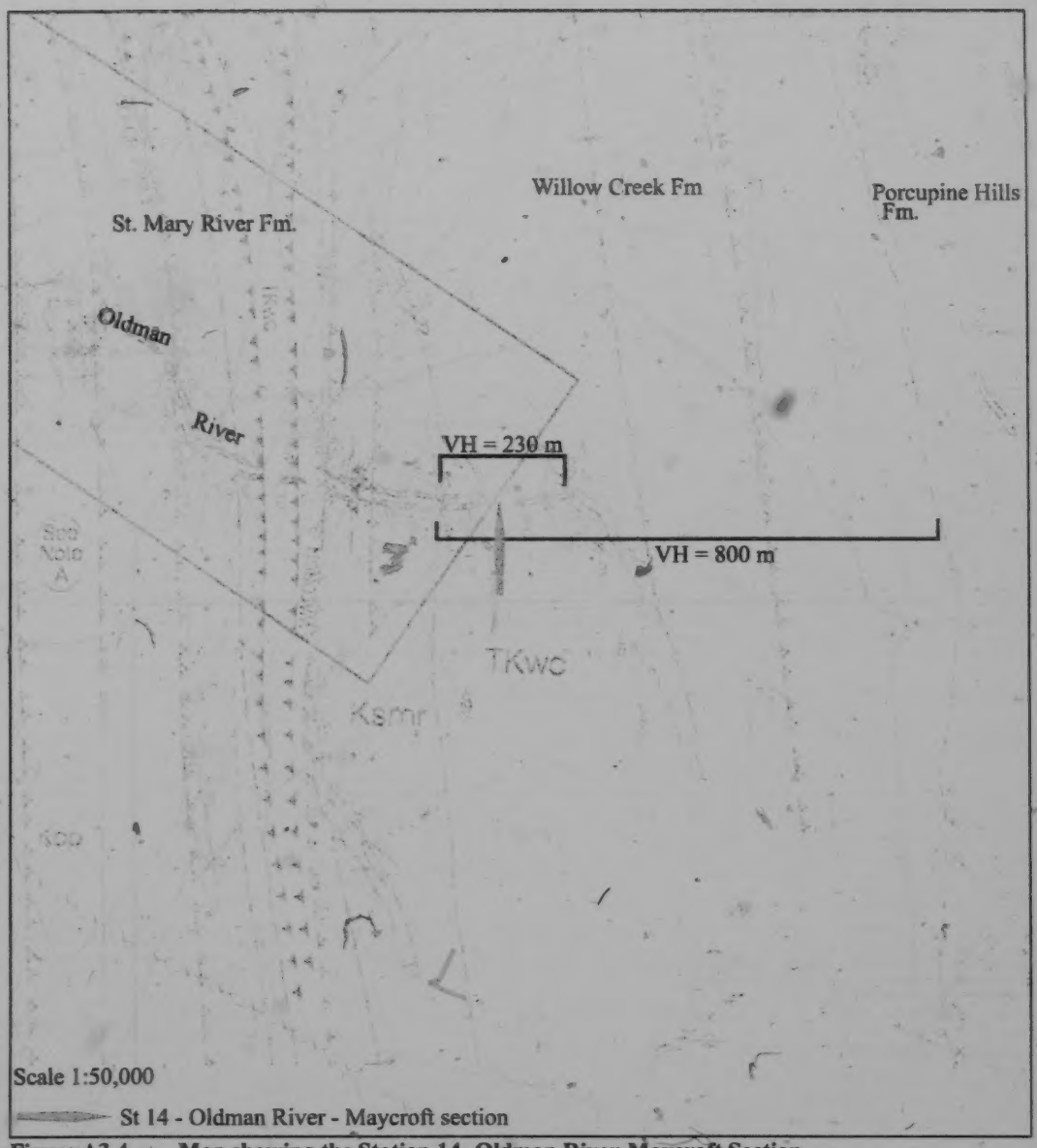

Figure A3.4 Map showing the Station 14- Oldman River-Maycroft Section

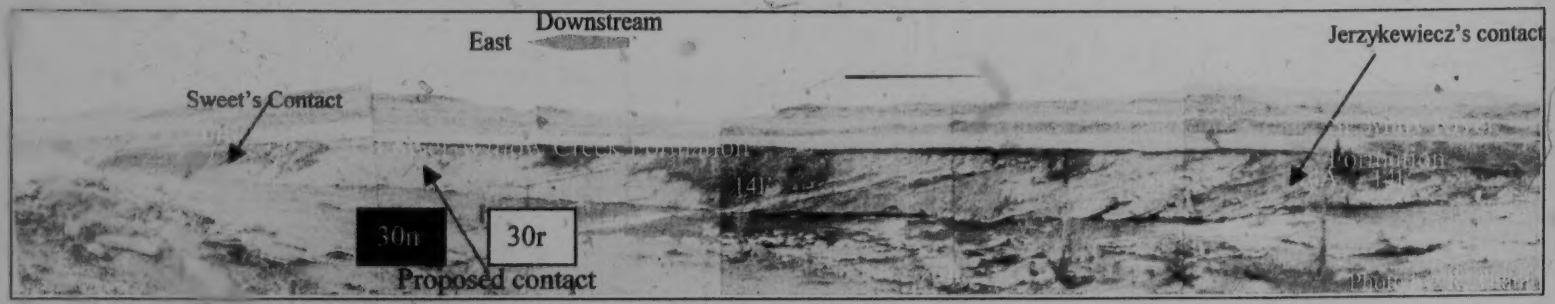

Figure A3.5 **Photograph showing the Station 14-Oldman River – Maycroft section.**

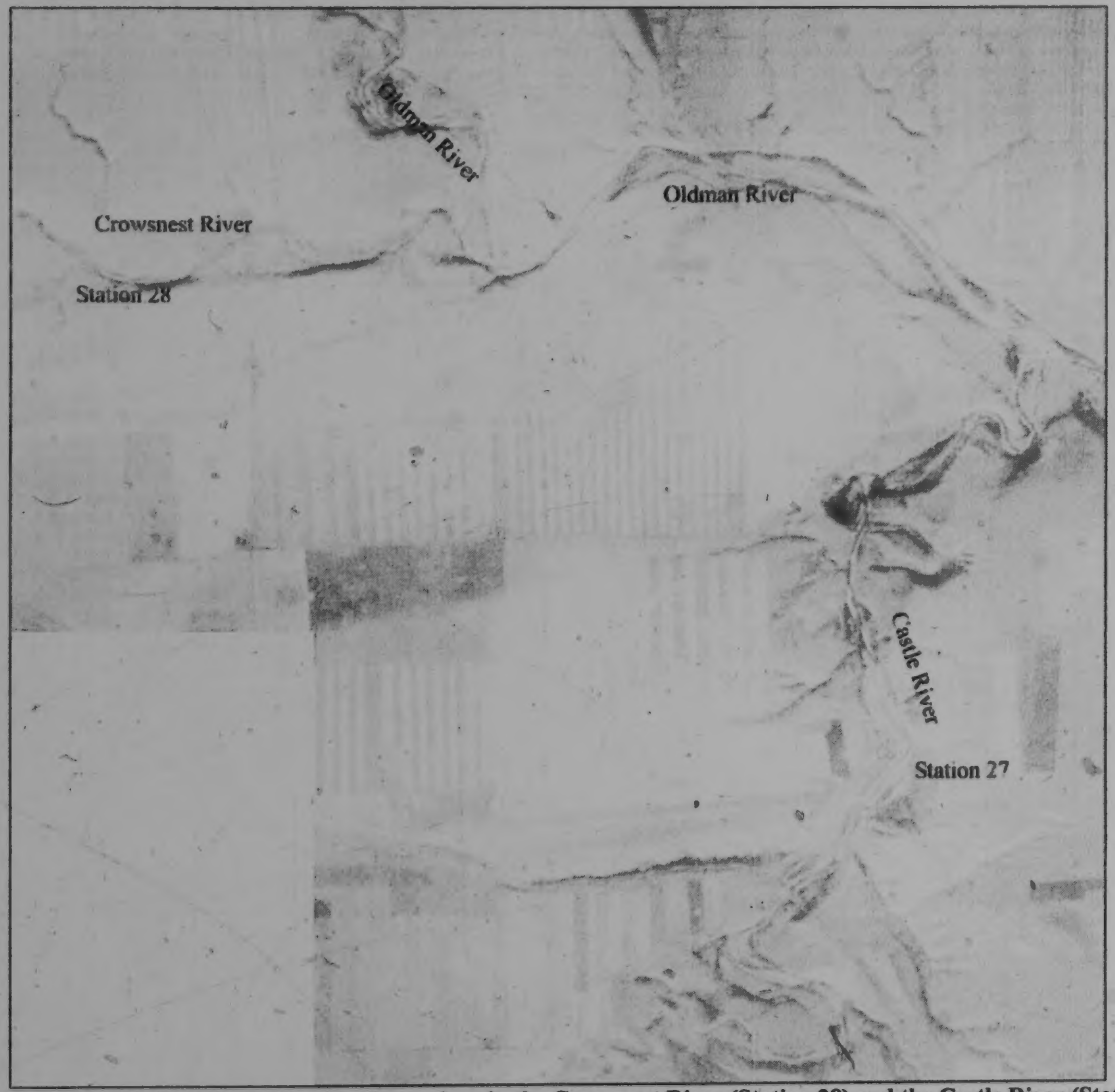

Figure A3.6 Airphoto showing the sections in the Crowsnest River (Station 28) and the Castle River (Station 27).

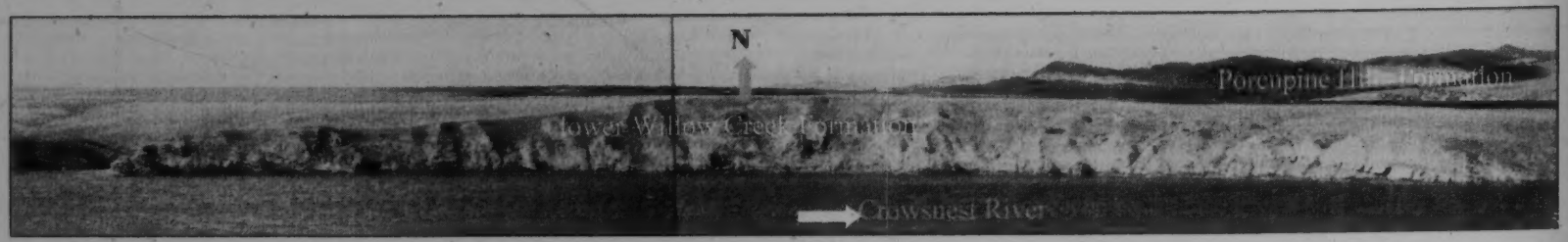

Figure A3.7 Part of the Oldman River Dam Reservoir - Crowsnest River section

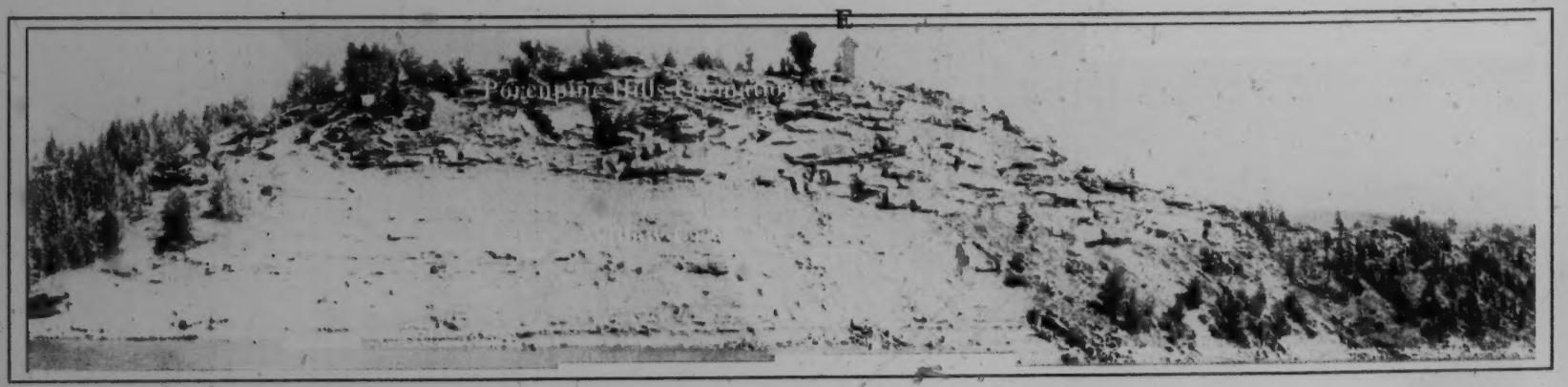

Figure A3.8 Photograph showing the Station 27- Castle River section.